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EVALUATION AND UPDATING OF LORAC
NAVIGATION SYSTEM ON MONTEREY BAY

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United States Naval Postgraduate School



THESIS

EVALUATION AND UPDATING OF LORAC
NAVIGATION SYSTEM ON MONTEREY BAY

by

Andrew Franklin Durkee

DEC 1969

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Evaluation and Updating of LORAC
Navigation System on Monterey Bay

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

A LORAC system of navigation has been established in the Monterey Bay area and is intended for use in the field of ocean sciences research. It operates on a phase comparison principle and provides highly accurate navigational fixes without complex timing circuitry. Short-term phase stability of the system was studied and methods of remote control and lane identification were investigated. Some equipment modifications were made to incorporate desirable features in the system, but further modernization may be necessary if long periods of continued use are expected. A general plotting program for the CALCOMP-563 plotter was written to produce chart overlays for existing navigational charts and is included as Appendix B. The overlays can be tailored to fit any scale chart in the area of intended operation and the inputs to the grid generation program can be varied if the system parameters are changed.

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I. INTRODUCTION

LORAC uses the principle of phase comparison of two radio frequency signals which have the same origin, but travel to the phase measuring equipment over two different paths. The radio frequencies, generated by two continuous-wave transmitters, produce, by heterodyning, audio signals between which the actual phase measurements are made. The two transmitters operate at frequencies f_1 and f_2 respectively and the audio frequency is $(f_1 - f_2)$. A reference signal is established by receiving and detecting this audio frequency at a fixed point and using it to amplitude modulate a third transmitter. This transmitter operates at a frequency f_3 and is called the reference transmitter.

A. POSITION FINDING

Positions are determined by the use of a mobile receiver. This receiver is tuned to the average frequency of f_1 and f_2 . It receives and detects the audio frequency $(f_1 - f_2)$ and this is called the position signal. The receiver is also tuned to the third frequency, f_3 , and the reference signal is detected. The phase angle between the position signal and the reference signal is measured. These signals were each produced by the same two continuous-wave transmitters, but traveled to the receiver over two different paths.

The phase of the reference signal at the reference transmitter will be constant because the transmitter is fixed. The amplitude

modulation on the carrier f_3 is of constant phase if the distance from the mobile receiver to the reference transmitter is not too great (less than 50 nautical miles). However, if the receiver is moved, the position signal changes phase quite rapidly because the relative phase of the two continuous-wave radio frequencies changes rapidly.

The phase difference between the position signal and the reference signal depends on the location of the mobile receiver. If the receiver is moved so that the phase difference remains constant, the path followed will be a hyperbola with the two continuous-wave transmitters as the foci. As long as the difference in the distances to the transmitters remains constant there will be no change in phase. If the receiver moves in a path other than this hyperbola, a change of phase will occur.

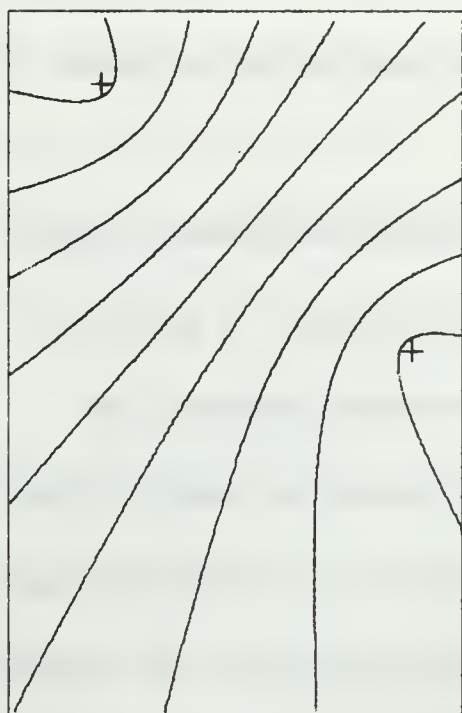
There is an infinite set of constant phase hyperbolas generated by the two continuous-wave transmitters. If a receiver is placed in the network, it will lie along one particular hyperbola of the set. The midpoint of the line joining the two transmitters is chosen as a reference. The unique hyperbola passing through this point (a straight line) is assigned an arbitrary value, and all other hyperbolas in the network are assigned values using this central hyperbola as reference. The central hyperbola and each hyperbola differing from the central hyperbola by 360 degrees of phase form the boundaries of LORAC lanes. As the receiver crosses one lane it indicates a phase change of 360 degrees. The location of the receiver within each lane can be

determined by measuring the amount of phase change since crossing the boundary. A hyperbolic network with lane boundaries is shown in Figure 1(a).

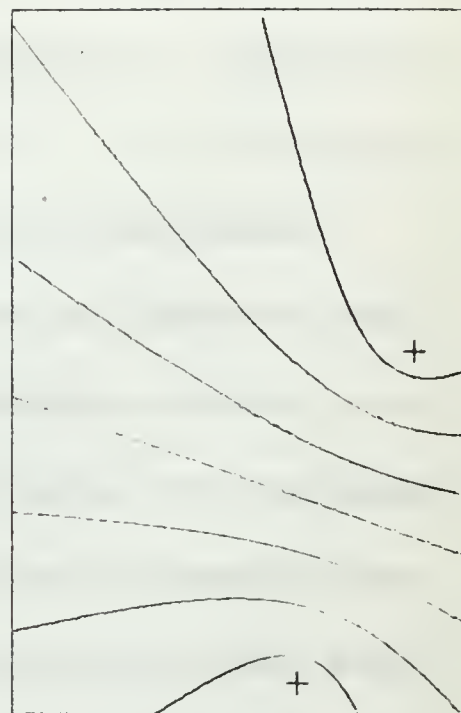
Absolute positioning has not been accomplished since location along a hyperbola determines only one line of position. A second line of position is obtained by duplicating the entire network just described. The second set of transmitters is located so that the two sets of hyperbolas form a positioning grid in the area of intended use. Figure 1(b) shows the second set of hyperbolas and Figure 1(c) shows the grid formed by superposition of the two sets. One focus is common to both sets of hyperbolas. One set of hyperbolas and its associated equipment is called the GREEN half of the system and the other is called the RED half. The mobile receiver makes two phase measurements, one for each half of the system. Each of these measurements corresponds to a line of position in the appropriate set of hyperbolas. The position of the receiver is determined by the intersection of these lines of position.

B. THE LORAC-A SYSTEM

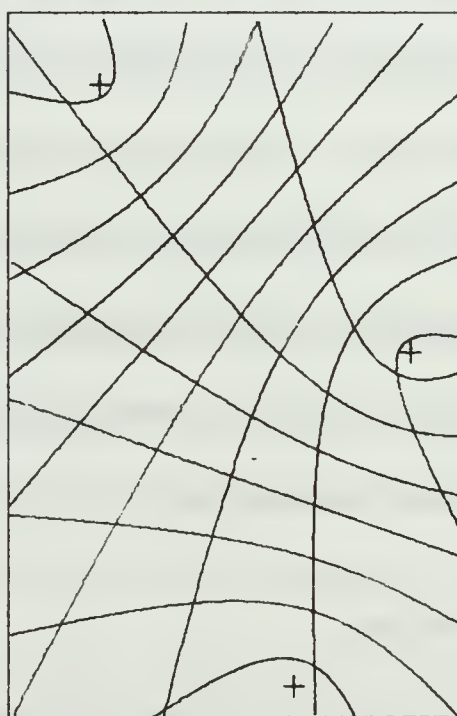
The basic LORAC system with two sets of hyperbolas would require six transmitters and four frequency channel assignments. LORAC-A offers a savings in equipment and frequency channels required. Three transmitters produce both sets of hyperbolas on a time-shared basis as shown in Figures 2 and 3.



(a)



(b)



(c)

Figure 1. Hyperbolic Grid System

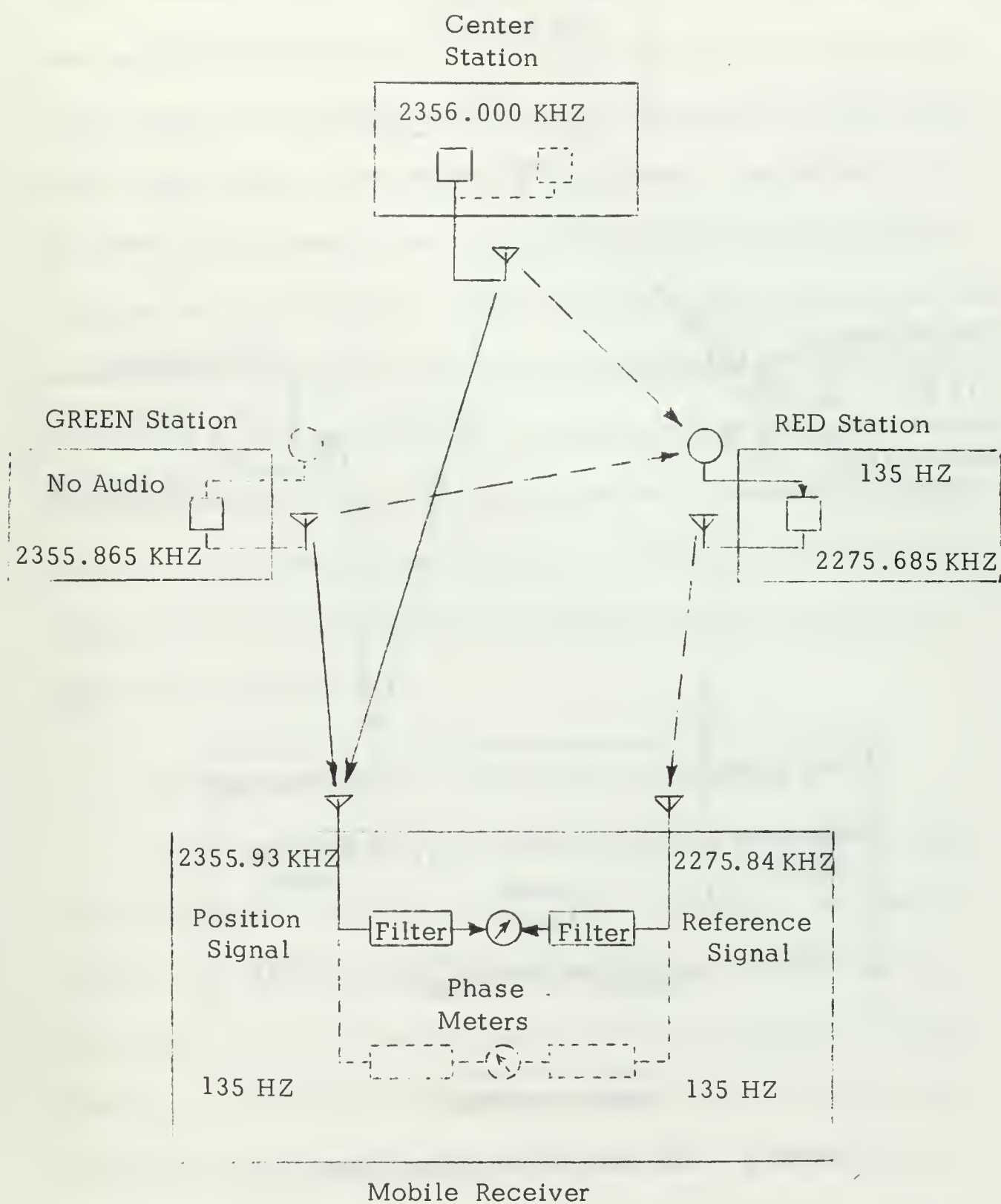


Figure 2. GREEN Half of Switching Cycle

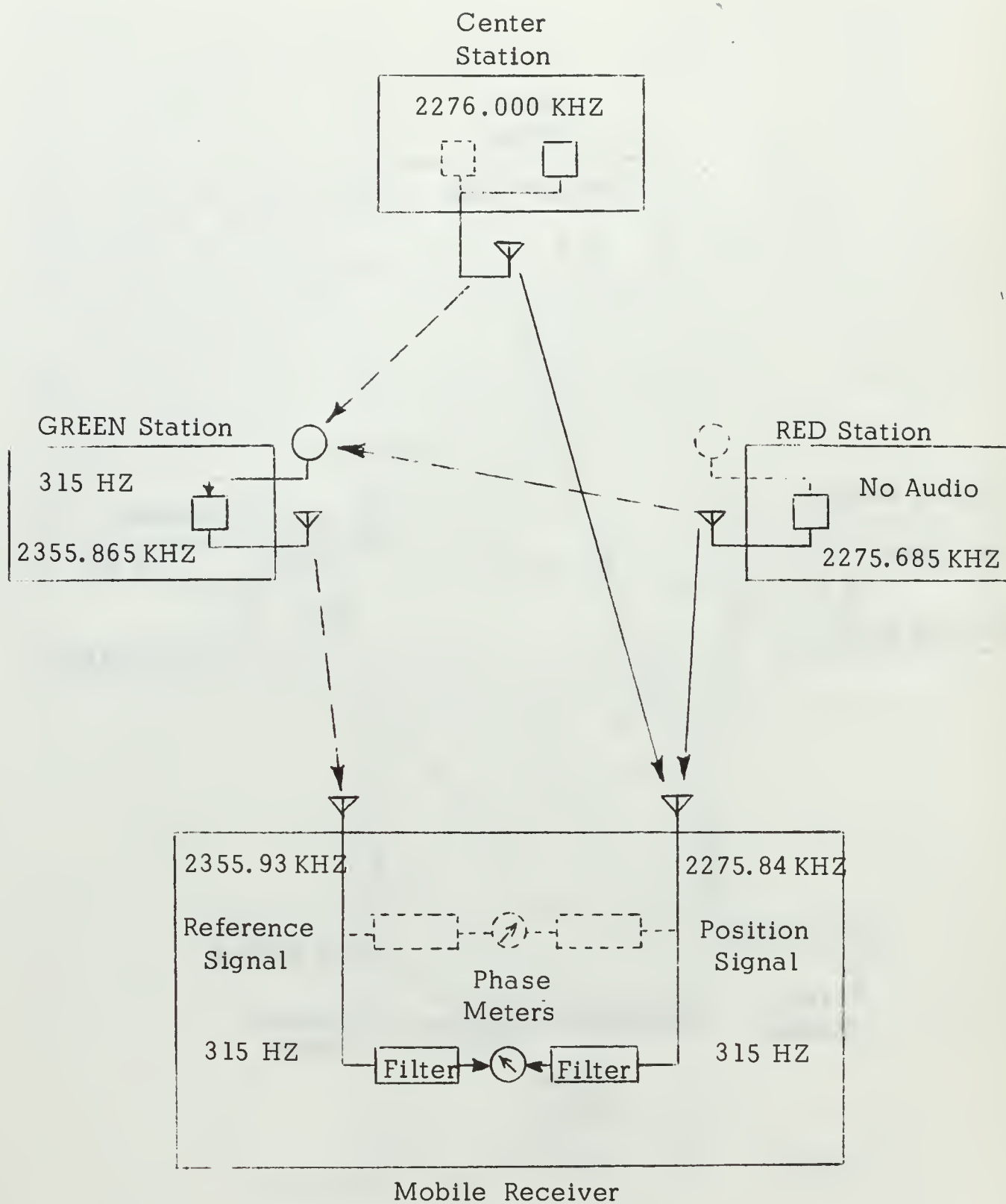


Figure 3. RED Half of Switching Cycle

During the GREEN half-cycle, the center station and the GREEN station transmit continuous-wave radio frequencies and the RED station acts as the reference transmitter. During the RED half-cycle, the center station and the RED station transmit continuous-wave and the GREEN station acts as the reference transmitter. The frequency of the center station determines the particular half-cycle in operation. Only one set of hyperbolas is being produced at any given instant and the center station switches periodically between two continuous-wave frequencies. The switching rate is rapid enough so that at the receiver it appears that both sets of hyperbolas are being produced simultaneously. The center station is a focus in both halves of the network, acting alternately with the GREEN and then the RED transmitter to generate the hyperbolas.

C. SYSTEM HISTORY AND EQUIPMENT DESCRIPTION

The present LORAC system was surplus and given to the Postgraduate School for operational use. The transmitters, receivers, recorder, and test equipment were manufactured by LORAC Service Corporation, a division of Seismograph Service Corporation, Tulsa, Oklahoma. Considerable time and effort was spent in restoring the equipment to operating condition. The equipment is about fifteen years old and uses tubes in most of the circuits. The transmitters are designed for a maximum output power of 300 watts. Four mobile receivers, one chart recorder, and numerous spare parts are available in the present system.

In 1968 LT Richard E. Shrum, USCG, undertook the system as a thesis project. Transmitters were installed in Santa Cruz, Moss Landing, and Monterey to provide LORAC coverage of Monterey Bay. His thesis, "Installation and Evaluation of LORAC Precise Navigation System," was used as a reference and to provide some of the ground-work for further investigations and testing.

II. SYSTEM PERFORMANCE

Performance of the system can be measured by observing two general parameters, stability and accuracy. Stability is measured by fixing as many of the variables involved as is considered practical and recording the variations due to the rest. Accuracy is measured by comparing theoretical receiver readings with those actually observed.

Stability measurements were made by establishing a monitor station in a fixed location and observing the variations in the receiver dial readings. Instrumental error was previously determined to be plus or minus one-half of a dial division (1/100th of a lane). This includes transmitter and receiver stability. Geometrical error is introduced by assuming that the earth is flat and the transmitting and receiving antennas are at the same elevation. This error for the vicinity of Monterey Bay was determined to be less than one meter and remains constant for a fixed receiver. Changes in the velocity of propagation will produce most of the error in a monitor station and the relative magnitude of these changes can be observed if dial readings are recorded over a period of time.

A. PHASE STABILITY MEASUREMENTS

The block diagram in Figure 4 shows the interconnection of components for data collection. The receiving antenna was a fifteen-foot whip mounted in a relatively clear area. No antenna coupler was used

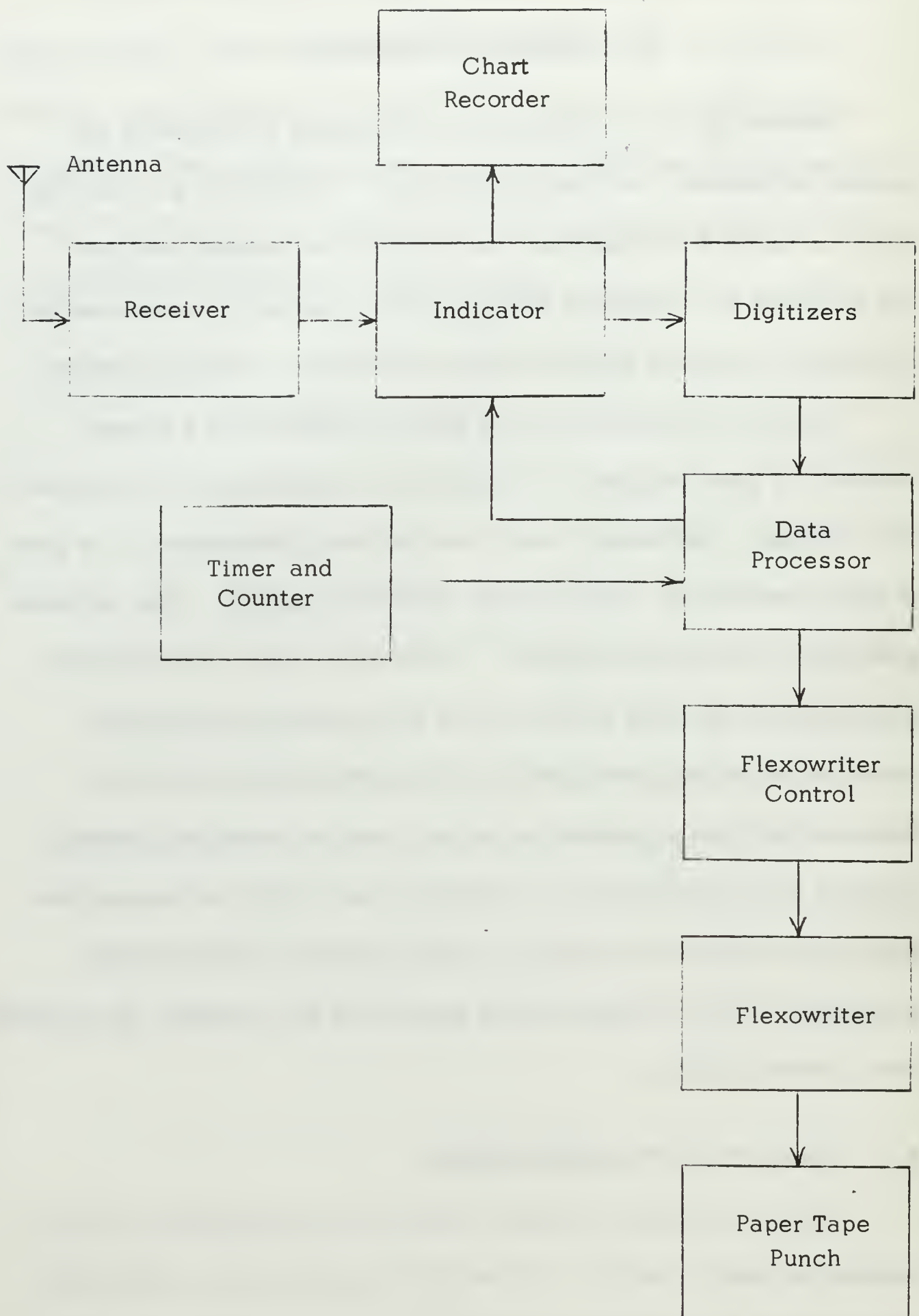


Figure 4. Monitor Station

with the receiver because signal strength was not increased with the coupler in the circuit. A shielded coaxial cable connected the antenna to the receiver. The shaft positions of the indicator unit were relayed to the chart recorder by synchro transmitters. These transmitters are included in the indicator circuit to drive external equipment. The recorder was used as a visual aid in evaluation of the dial reading variations and as a backup device in the event of a failure of the primary method of data collection.

The primary method of data collection was a digitizer which converts an analog shaft position to a digital readout. Two digitizers were connected directly to the indicator dial shafts by flexible control cables and couplings. Each has a resolution of 3.6 degrees, or 100 increments for one revolution. The output to the data processor can vary from 000 to 999 corresponding to ten revolutions of the digitizer shaft. The data processor converts each digitizer reading to serial commands to a flexowriter, first the GREEN reading, then the RED. Each dial on the indicator has a lane counter which changes with each revolution of the pointer. This counter indicates the lane location of the receiver and the pointer indicates the fractional location within that lane. The digitizers are calibrated so that the first digit corresponds to the last number on the lane counter. The second and third digits correspond to the pointer reading in hundredths of a lane. The flexowriter generates a typed copy of the readings and at the same time punches the data on paper tape. The typed copy was used as a check on the digitizer accuracy and the paper tape was used for processing the data.

A timing and counting unit was built to control the frequency of the observations and tabulate the number of readings taken during the recording period. A frequency of one observation per minute was considered more than adequate to detect a change in the average velocity of propagation. Random variations from minute to minute were assumed to be generated by noise superimposed on the radio frequency signals. This noise was taken into consideration in the data processing program.

1. Data Processing

A computer program has been written to process the data tape punched by the flexowriter. The complete program is included as Appendix A. Processing was done on a CDC-160 digital computer which accepts punched paper tape as input data. The CDC-160 has available a small FORTRAN II compiler stored on magnetic tape. The desired FORTRAN II program is punched on paper tape with a flexowriter, adhering to the format in the CDC-160 FORTRAN manual. This tape is called a source tape and is read by the compiler to produce an object tape. The object tape contains all the subprograms necessary for execution of the program. The source tape is no longer needed unless changes are to be made in the program. Each time the program is to be run all that is necessary is to read the object tape and any data tape required by the statements in the program. Output from the computer is on paper tape and can be read by a flexowriter to produce a typewritten copy.

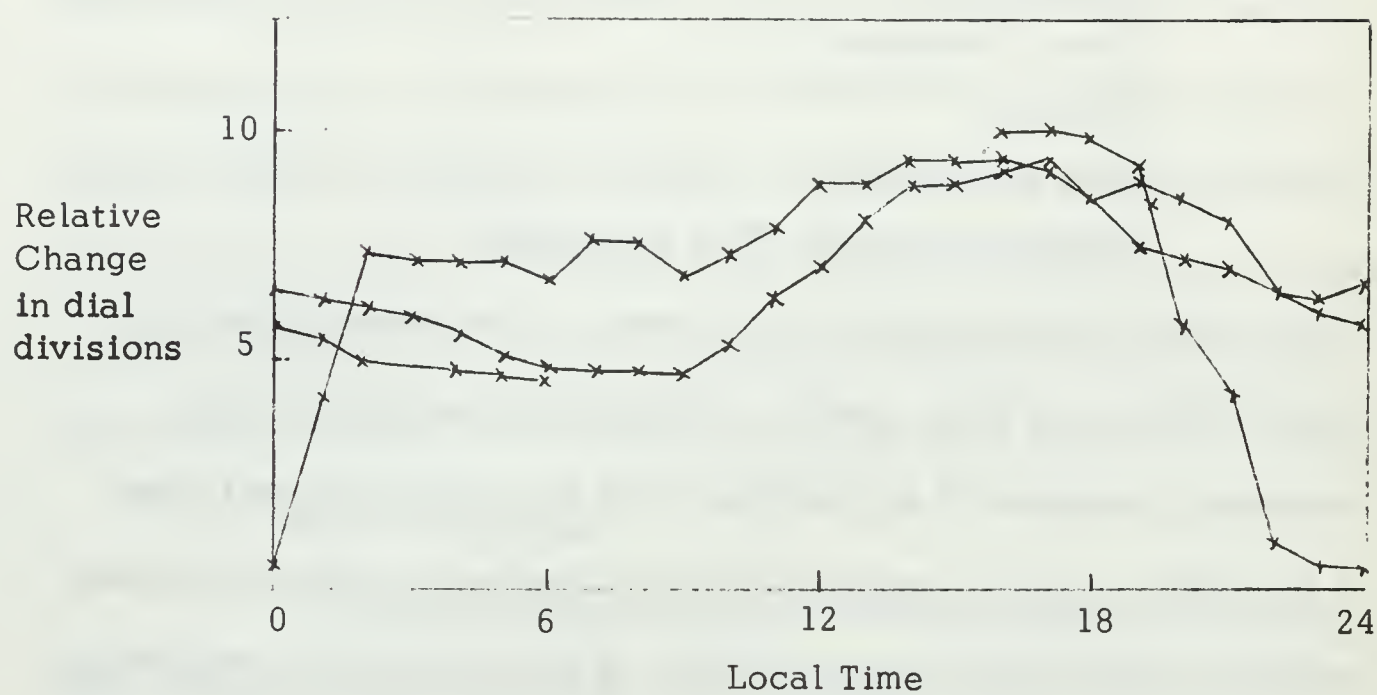
The program written to process the data from the digitizers handles the readings in one-hour segments. The following computations are made for each block of 60 readings:

Mean (average)
Maximum
Time of maximum
Minimum
Time of minimum
Standard deviation (RMS component)

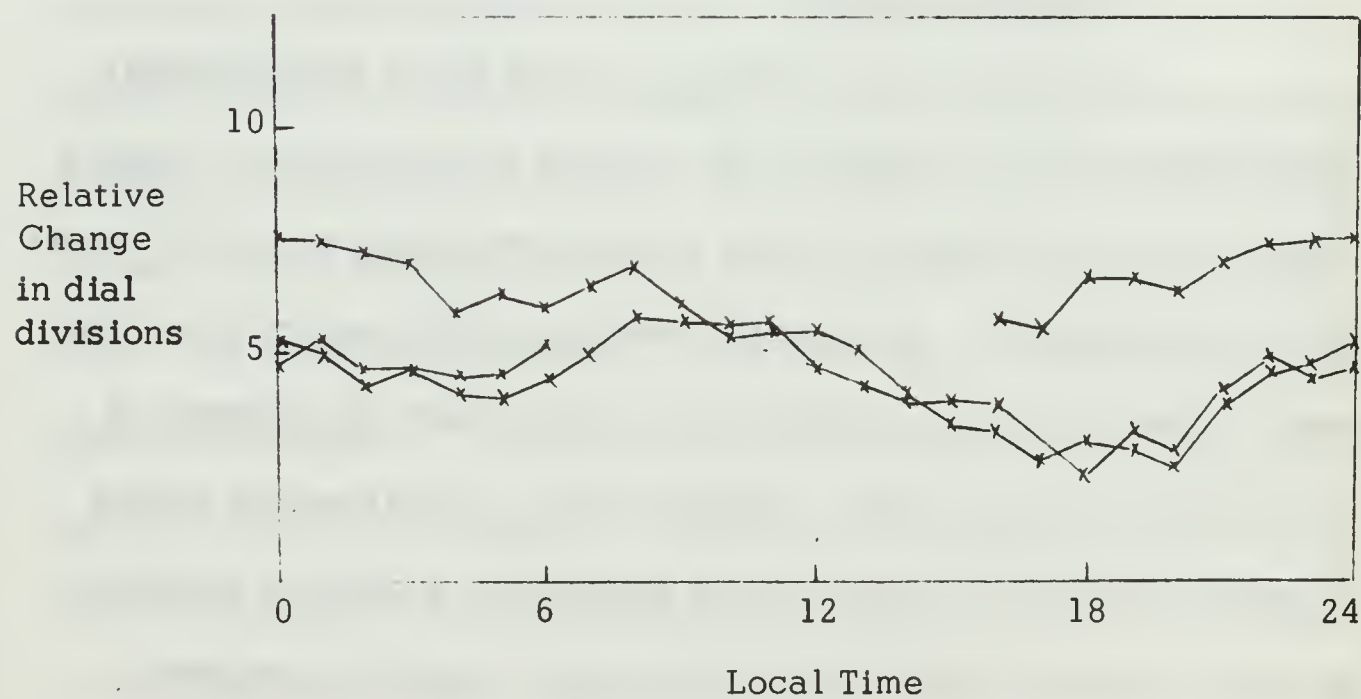
The standard deviation can be considered a noise error similar to a noise voltage on a D.C. level. It should be interpreted as the expected fluctuation of any reading about the average for that hour. If the RMS, or noise, error is relatively constant or varies with some periodic pattern over a regular interval of time, then some predictions can be made as to the expected noise level at any given time. Similar predictions may be possible for the average values.

2. Evaluation of Data

Variations in the average value of phase meter readings should reflect direct changes in the velocity of propagation. Figure 5 shows a plot of average values for a typical recording period (62 hours) in 24-hour intervals. All readings were taken with respect to an arbitrary reference since the charts for the system were not prepared at the time the data was taken. The plots show a considerable amount of drift during the first twelve hours followed by a periodic variation pattern. The initial drift can be attributed to a period of receiver stabilization and was evident in most of the extended periods of data collection. The periodic variations can be attributed to changes in velocity of propagation. The two plots do not show the same pattern



(a) GREEN Network



(b) RED Network

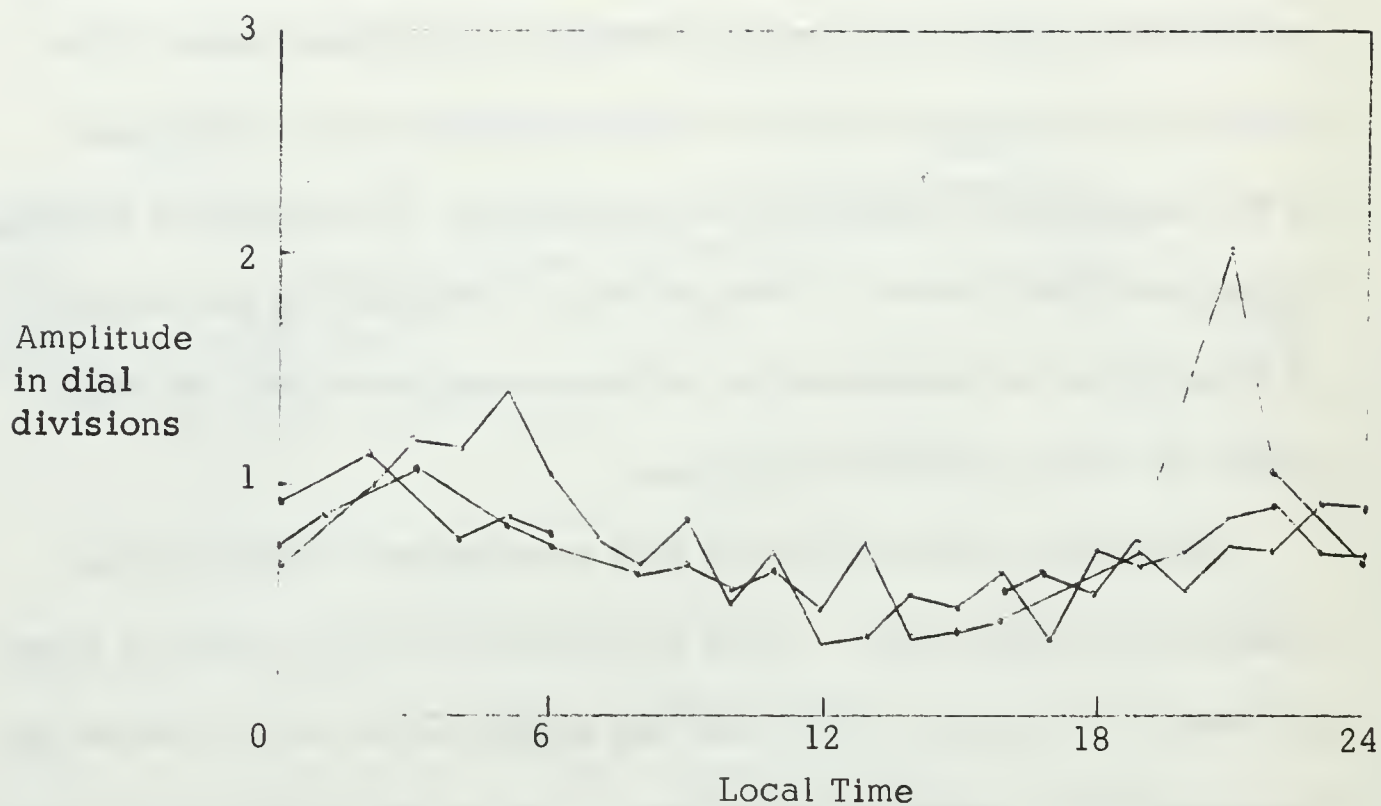
Figure 5. Average Phase Variations

for the RED and GREEN halves of the system. This is explained by the fact that the signals travel to the receiver over different paths. The direction and magnitude of phase change depends on the orientation of the receiver with respect to the transmitters. The amount of variation in phase for both halves of the system due to changes in the velocity of propagation was determined to be plus or minus two dial divisions within the area of intended operation.

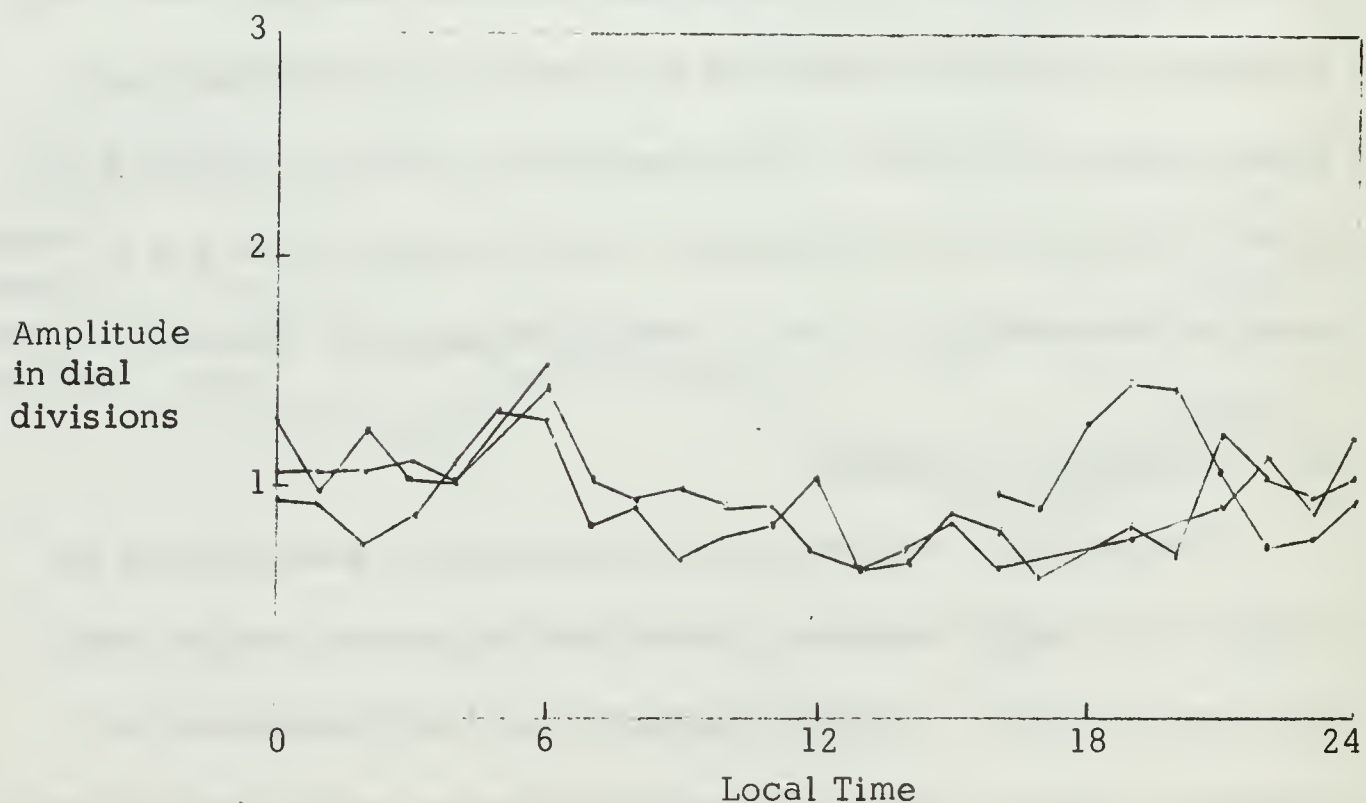
Variations in the calculated RMS error reflect changes in the noise level of the system. A plot of error for a 24-hour period is shown in Figure 6. The plots for the RED and GREEN halves of the system are very similar and appear to be periodic. The maximum noise level occurs between 2000 and 0600 and the minimum between 0800 and 1400. The error due to noise was determined to be about one dial division for a reading taken at any time. Closer predictions could be made, but the noise level at any one time changes widely from day to day and it would be more reliable to use an overall average as an estimate.

B. FREQUENCY STABILITY

The oscillator frequencies of the transmitters were initially set with a highly stable frequency counter and periodically verified with the same instrument. System accuracy is not highly dependent on frequency stability; in fact, the audio frequencies would have to drift outside the filters to produce any noticeable error. The center station was found to be the most stable of the three transmitters. After initial adjustment, the two frequencies of the center station did not drift



GREEN Half of Network



RED Half of Network

Figure 6. RMS Error Variations

more than plus or minus two cycles. The center station frequencies were considered constant during the remainder of the evaluation period.

After any adjustment was made to a transmitter, the audio frequencies were monitored to detect any drift. Frequency measurement was made by using the audio output from the monitor circuits in a receiver together with an adjustable audio oscillator output to produce a stable Lissajous pattern on an oscilloscope. A counter was used to measure the oscillator frequency. The audio signal from the system could not be measured directly due to the switching cycles. Most of the frequency drift occurred within six hours after energizing the transmitters. After the first few hours of operation, drift was negligible and settled to a rate of one or two cycles per week. Therefore, the best operation results if the oscillators are kept in operation. Adjustments in frequency during long periods of operation do not affect the drift rate and each oscillator should not have to be adjusted more than once a month.

C. EQUIPMENT RELIABILITY

Prior to energizing the entire system, each of the three transmitters were inspected for any visible defects in cable connections, antenna couplings, or similar items. Fuses were checked to insure that the correct size was being used. Prior to applying full power to the stations a variac was used to apply a low voltage to the power supplies and bring the units up slowly to the required line voltage. This allowed a period of time for moisture to evaporate and any

defects in the heater circuits to be observed. This precaution was used when energizing any of the transmitters after an inoperative period.

The entire system was placed in operation in August 1969 and as of November 1969, has been operating about 50% of the time. The inoperative time has been due to occasional failures and testing periods. Failures of the stations were due primarily to aging components and exposure to moisture. The transmitter at Santa Cruz had the most failures and this was attributed to its location at the end of the municipal wharf. Moisture was allowed to accumulate during the eight-month period that the system was not in operation. No single component in that transmitter was at fault. In contrast, the transmitter at Moss Landing is located in a furnace room which remains relatively warm and dry. Similarly, the transmitter in Monterey is well protected and a reasonable distance from the shoreline. Failures in the latter two stations have been infrequent, and mostly tubes and fuses have been at fault.

A spare parts box has been made up from the numerous spares available for the system. It contains tubes, fuses, and a few miscellaneous parts for the transmitters. This box is kept in the transmitter building at Monterey along with appropriate test equipment.

During the tuning of each transmitter about half the maximum power was coupled to the antenna. This was found to produce sufficient signal strength to operate the receivers in the Monterey Bay area. If operation is to be outside this area, additional power is available.

Operation is efficient and the standing wave ratios of the transmitting antennas are kept under 1.50. These ratios can be reduced if maximum power output is desired.

III. CHART OVERLAY PREPARATION

If the LORAC system is to be used for absolute position finding, then charts for the network must be prepared. If LORAC is used for repeatability of position, no chart is needed since all that is necessary is to move the receiver until the dials indicate a previously recorded reading.

A. CHOOSING A COORDINATE SYSTEM

The mathematical equations for the hyperbolic constant phase contours can be written in a number of coordinate systems. The simplest to use in a digital computer program is a two-dimensional rectangular coordinate system with perpendicular axes and identical scales in both directions. Most navigational charts, however, are constructed using a mercator projection and the result is a set of geographical coordinates. A hyperbolic grid cannot be conveniently constructed in geographical coordinates since the equation for a hyperbola in this system can only be approximated. A solution to the problem is to calculate points along a hyperbola in a rectangular coordinate system and then convert each point to geographical coordinates. LORAC grids are commonly generated in Universal Transverse Mercator (UTM) coordinates, a rectangular system with units of meters. Army Map Service charts, in UTM coordinates, are available for the Monterey Bay area and the coordinates of the transmitting sites can be easily estimated.

B. POINT GENERATION PROGRAM

A computer program has been written to generate points in the LORAC network for plotting, and has been used on the SDS-9300 digital computer. It follows the general description for generation of hyperbolic grid charts found in the Computer's Manual published by the LORAC Service Corporation. The program outputs data points on magnetic tape for plotting on a CALCOMP-563 plotter and is flexible enough to allow updating if the transmitting antennas are moved or the frequencies changed.

1. Input Data

The following information is read by the program into the computer from data cards:

GREENX, GREENY	Coordinates of the GREEN station (UTM)
CENTERX, CENTERY	Coordinates of the center station (UTM)
REDX, REDY	Coordinates of the RED station (UTM)
FREQ (1)	Frequency of the GREEN transmitter (hz)
FREQ (2)	Frequency of the RED transmitter (hz)
CENFR (1)	Frequency of the center station when operating with the GREEN station (hz)
CENFR (2)	Frequency of the center station when operating with the RED station (hz)
FREQM (1)	GREEN modulation (audio) frequency (hz)
FREQM (2)	RED modulation (audio) frequency (hz)
VELPROP	Velocity of propagation
L1	First row of conversion tables to be read
L2	Last row of conversion tables to be read
CI, CVII, CVIII, CIX, CX	One row of conversion tables

The dimensions and constants of the LORAC network are then calculated and arbitrary lane numbers are assigned to the center lane in each half of the network. The following chart parameters are introduced:

XMIN	The western boundary of the chart in geographical coordinates
XMAX	The eastern boundary of the chart
YMIN	The southern boundary of the chart
YMAX	The northern boundary of the chart
XSCALE	Scale of the chart in the X direction
YSCALE	Scale of the chart in the Y direction
DELU	Determines point density
UMAX	Determines size of the network generated
M	The interval of plotted lanes

The chart parameters are read from a single data card and a set of points for a complete chart is generated by each data card included in the program deck. Using magnetic tape as the output medium, there is essentially no limit to the number of sets of points that can be generated with one program run. The lane numbers of the points generated are listed by the line printer along with the graph number and the limits of the graph. The coordinates of the transmitter sites are also written on the magnetic tape for use in a point-plot. The entire program does not have to be rerun to duplicate a chart since the plotter is not an on-line output device and the data for the charts is stored on magnetic tape.

2. Subroutines

SUBROUTINE CONVERT is used in the main program to convert each hyperbolic set of points from UTM to geographical coordinates.

The subprogram is written using 36-00N and 123-00W as the origin for any point to be converted. A row of the conversion tables must be read into the program for every minute of latitude in the desired chart and linear interpolation is used for values between each minute. UTM coordinates are calculated to the nearest tenth of a meter and the conversion process carries out calculations to the nearest hundredth of a second of latitude (about one foot), losing little or no resolution in the conversion process.

The main program retains only those points that lie within the boundaries of the desired chart, and stores all lanes with more than one point. Since the latitude and longitude scales are not the same on a mercator projection, the horizontal units are reduced by the appropriate scaling factor found in mercator construction tables.

SUBROUTINE TAPEOUT prepares and writes the points on magnetic tape. The SDS-9300 is a 24-bit word digital computer which uses 2's complement arithmetic and the small computer that controls the plotter, the CDC-160, is a 12-bit word computer which uses 1's complement arithmetic. Some changes in format are necessary so that the output from the SDS-9300 can be read by the CDC-160. The subroutine scales the chart according to the values of XSCALE and YSCALE, limits the output points if they are too large for the CDC-160, and stacks the coordinates for more efficient use of magnetic tape. Each data point is stacked so that the first twelve bits of the SDS-9300 word contain the X coordinate and the last twelve contain the Y coordinate. The result

is a higher density of output points and an easier format for the CDC-160 to read. This subroutine can be used with any set of points and called with the following arguments:

X	The horizontal coordinate of each point
Y	The vertical coordinate of each point
IPC	The number of points
XSCALE	Scale in the X direction
YSCALE	Scale in the Y direction
MWIDE	Width of the horizontal field before scaling
MHIGH	Height of the vertical field before scaling

After scaling, the values of X and Y will be limited to plus or minus 2,047.

C. PLOTTING PROGRAM

The SDS-9300 computer does not have a plotter as an output device, so the points to be plotted were stored on magnetic tape. A CALCOMP-563 plotter was available and offered a plotting surface 30 inches wide and up to 100 feet in length. The plotter is controlled by commands from a CDC-160 computer and a general program was written for plotting lines, points, borders, and axes. The program will be discussed in some detail since no previous program was available and it may prove useful as a reference for future use of this system.

The CALCOMP-563 plotter will accept any one of ten instructions from the CDC-160:

Move carriage 0.005" in +X direction

Move carriage 0.005" in -X direction

Rotate drum 0.005" in +Y direction

Rotate drum 0.005" in -Y direction

Four combinations of the X and Y commands above to produce diagonal motion

Move pen down to paper

Move pen away from paper

Any program written must consist of combinations of these building blocks repeated the required number of times to move the intended distance and the intended direction.

The PLOT program will accept data points from any of the following sources:

Output from the CDC-160 FORTRAN II package

Paper tape output from the SDS-9300

Magnetic tape output from the SDS-9300

Manual entry from the CDC-160 console

The CDC-160 FORTRAN II package was described briefly in Chapter II.

Using an OUTPUT statement in a program produces a punched paper tape in binary which can be read into a plotting program. Binary output is also produced by the SDS-9300 paper tape and magnetic tape outputs if an unformatted WRITE statement is used in a FORTRAN IV program.

These last two formats are identical except for the END FILE characters which are used to separate sets of points. Data points may be entered in memory at the CDC-160 console, but this is a time-consuming process if more than a few points are needed.

The PLOT program selects the proper input device (paper tape reader or magnetic tape unit) then reads and stores all the points in memory for one line or point plot. Figure 7 illustrates the major control instructions in the program and the use of various subroutines. The pen is moved to the initial point and lowered to the paper. If the point-plot mode was selected, the pen draws a cross through the point and moves away from the paper; if the line-plot mode was chosen, the pen remains on the paper. The direction to the next point is determined by a slope calculation, and this slope determines which of sixteen different subroutines moves the pen. Each subroutine covers about twenty degrees of arc about the pen and is made up from the basic building blocks to move in a direction to bisect the arc. The slope is calculated after each movement of 0.005" and the appropriate subroutine is again chosen. This technique results in a relatively smooth curve if the line-plot is used with a data density of four or five points per inch. Much smoother curves are obtained as the density increases to the limit of 200 points per inch.

A general plotting program should utilize the entire 30-inch width of the paper and the largest integer that can be stored in the CDC-160 is 2,047 (positive or negative). A plotter step size of 0.005" makes available 200 addressable points per inch and if both positive and negative integers are utilized, the maximum graph width and height is 20.47 inches. To expand the graph size to the limits of the paper width, the addressable point density was reduced to 100 points per inch.

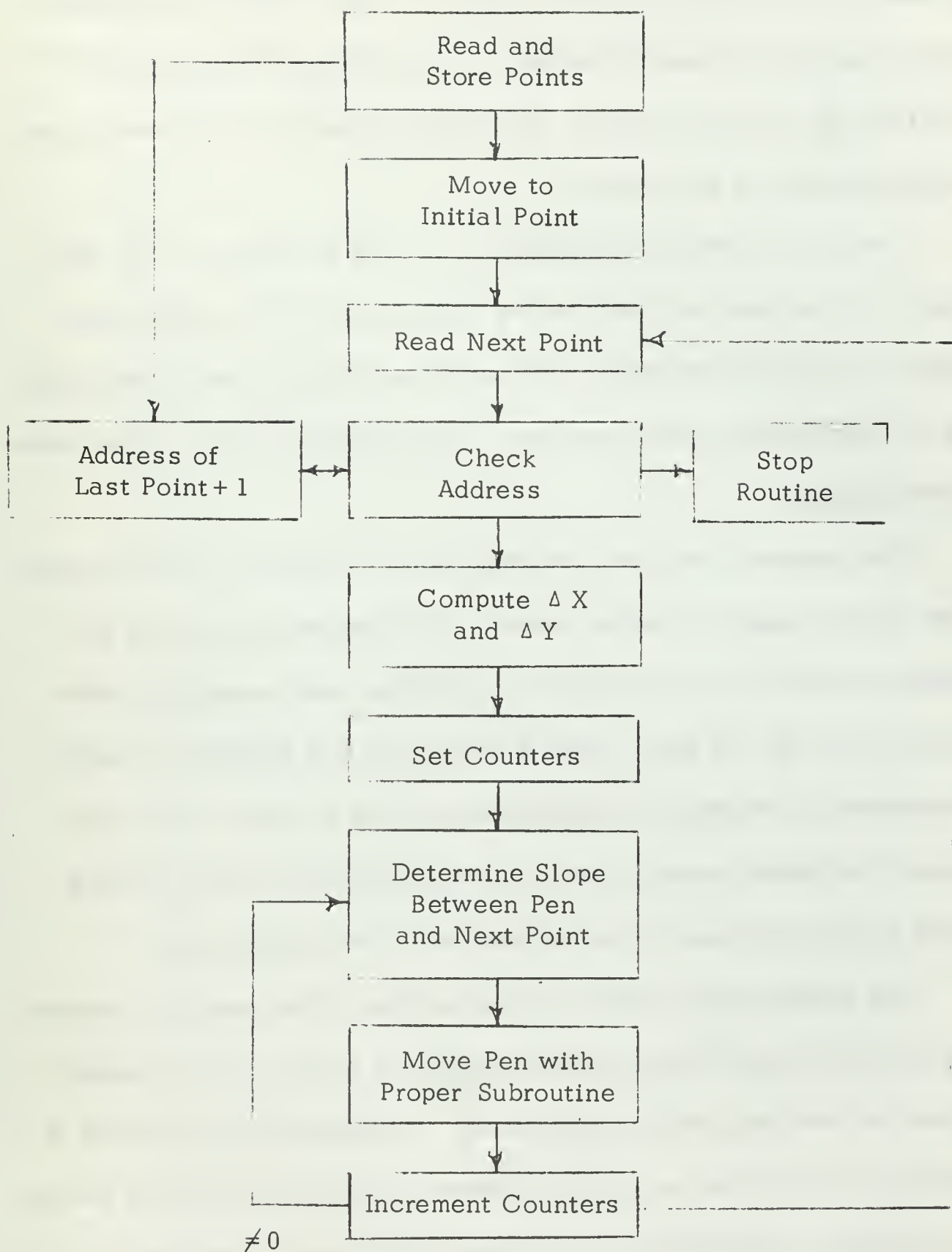


Figure 7. Plot Program Flow Diagram

This is done in the program by giving each pen movement command twice or doubling the distance between adjacent points. The higher density plotting mode is retained, however, and can be used if the graph is less than 20.47 inches square. The point density is determined by the starting address of the program.

Two graph sizes are available as a result of the change in point density. One graph is 20.47 inches square and has 200 addressable points per inch and the other is 30 inches wide, 40.94 inches high and has 100 addressable points per inch. The origin is located in the center of both graphs.

Two plotting modes were written into the program, one for plotting lines and the other for plotting points. Either mode can be used with either graph size. The subprogram for plotting lines reads and stores all the points for one line, draws a continuous line through the points, then returns to the origin and reads the next set of points. The subprogram for plotting points reads and stores one set of points, draws a plus sign at each point, then returns to the origin and stops.

The overall program has some restrictions. The maximum number of points that can be stored at any one time is 1,275, but any number of lines or sets of points can be plotted. The initial point on a line or the first of a set of points can be anywhere on the graph, but the change in successive coordinates cannot exceed 3.41" due to the slope calculating routines. This does not present a problem when drawing lines since the data density should be a few points per inch for a smooth curve.

It must be kept in mind, however, when using the point plot. An example of a prepared chart overlay is shown in Figure 8, illustrating the results of both the line plot and point plot modes.



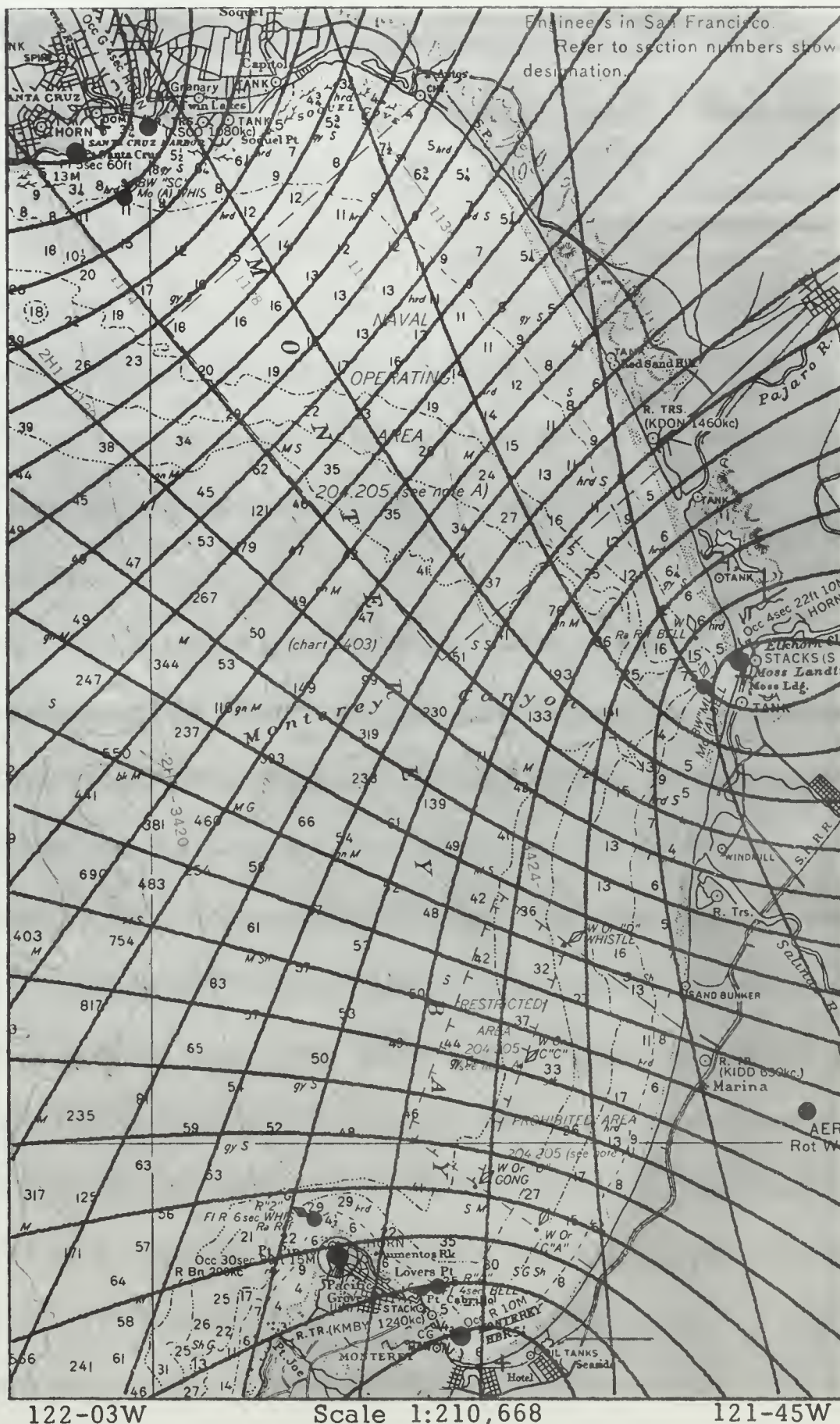


Figure 8. Sample Chart Overlay

IV. UPDATING THE SYSTEM

The present LORAC-A system was the first type in a series of hyperbolic phase comparison navigation systems manufactured by LORAC Service Corporation. Newer systems incorporate additional features such as lane identification and remote control to eliminate lane ambiguity and to make operation easier. The possibility of adding these two features to the existing system was investigated.

A. MODIFICATION AND TESTING

There are four receiver-indicator units for use with the system and each receiver was connected to its indicator by an eight-foot shielded cable. The two units were not easily separated and some difficulty was encountered in transporting the receivers. The cables were removed from three of the receivers and connecting jacks were mounted on the rear of the receivers and indicators. Short cables with connectors were made up to join the two jacks and these allow separation of the receiver and indicator when transporting or repairing. This modification also allows interchangeability of units which before was not easily accomplished.

A LORAC chart recorder for the system was repaired and an additional chart recorder was modified for use with the system.

Installation of a LORAC receiver on the Naval Postgraduate School research boat has been desirable since the navigation system was placed

in operation and some projects conducted in Monterey Bay require precise fixes, repeatability, and station keeping. A receiver was used on this boat in the past and some difficulty was experienced in positioning the indicator so that the dials were clearly visible to the helmsman. Disassembly of the indicator unit was considered undesirable due to the number of connections between components.

A remote indicator unit has been constructed to duplicate the dial and counter readings of the indicator. This unit has four synchro repeaters, two for the dials and two for the lane counters, which are driven by two synchro transmitters in the indicator. A multiple-conductor cable is connected to the output terminal board of the indicator.

A small chart recorder was adapted for use with the on-board receiver and a record of readings can be maintained. The recorder is connected by a six-foot cable to a jack mounted on the back of the indicator.

B. REMOTE CONTROL

It is desirable to place the three transmitters in a standby condition when the system is not being used. Standby condition may be defined as consisting of all heaters and blowers operating in the power supply, modulator, and RF amplifier, and the reference receiver and oscillator in full operation. These conditions insure frequency stability and minimize unnecessary radiation and warm-up time when full operation is desired. Available methods of remote control require

additional frequency assignments or leasing of landlines. The method proposed uses the frequencies already in use and has proven successful in laboratory tests.

Each mobile receiver contains two signal loss alarm circuits to indicate failure of either audio signal of the network. When a transmitter fails or signal strength falls below a certain level, an alarm lamp is energized on the indicator front panel. The signal loss alarm circuit uses the AGC level in the audio portion of the receiver to bias the grid of a relay control tube. A small relay in the plate circuit of this tube is held open under normal signal conditions. If the signal fails, the AGC voltage changes, the tube is cutoff, and the relay closes providing a return to ground for the indicator lamps.

The reference receivers in the transmitters at Santa Cruz and Monterey are essentially one half of a mobile receiver. The AGC circuits are the same but no signal loss alarm is used. The circuit boards are identical to those in the mobile receiver, however, with relay socket, tube socket, and wiring to a terminal strip. By simply inserting the proper tube and relay, the circuit operates the same as in the mobile receiver. This small relay can now be used to control the high voltage switches in the modulator and power supply.

Remote relays can be put in parallel with the high voltage switches and controlled by the relay in the reference receiver. This was done with the transmitter in Santa Cruz. The power supply in the reference receiver provides 250 volts d.c. which is used through dropping

resistors to energize the remote relays. The small relay in the reference receiver is single-pole, double-throw and has contacts rated at 250 ma. The relays used in the modulator and power supply each require five milliamps to energize and were wired in series to increase the voltage drop. Connections between units were made by using the spare wires in the wiring harness.

Limited success was attained with this circuit as a remote control device. The presence of an audio signal produced by the transmitters in Monterey and Moss Landing will hold the relays closed and keep the Santa Cruz transmitter in operation. When the signal is lost, however, the receiver noise level is high enough to also trigger the relays. The receiver used in the laboratory tests had a much lower noise level. Since all the circuit boards are interchangeable, it may solve the problem to exchange the AGC FILTER circuit boards in the two receivers.

This method of remote control has proven in theory that the presence of one signal is sufficient to control another. If the Monterey transmitter was placed in the standby condition, the loss of audio would be detected by the receiver at Santa Cruz and that transmitter would be placed in standby. The receiver would remain on and would be able to energize the rest of the units if the audio signal was again detected. If a similar circuit was placed in the transmitter at Monterey, then both transmitters could be controlled from the center station at Moss Landing. The system could also be controlled from one of the end stations but a receiver would have to be installed at Moss Landing.

C. LANE IDENTIFICATION

The LORAC-A system of position finding contains some lane ambiguities. Unless continuous reception and tracking of the signals is maintained, there is a possibility of losing track of the lane in which the mobile receiver is located. To reset the receiver to the proper lane number, its position must be known to within one lane width. On the baselines this is most critical since the lane widths are at a minimum of about 65 meters. Normal navigation methods such as radar, RDF, or LORAN do not offer this degree of fineness and some other method must be used.

Some methods of lane identification were investigated using the system itself. If another set of hyperbolic grids could be established with a lane width about ten times that of the basic system, it would be possible to use first a coarse lane reading then a fine lane reading for position finding.

One such method is based on a time difference principle similar to LORAN A. The end stations are transmitting continuously either CW or amplitude modulated. The center station switches periodically between two frequencies and the presence of the center station frequency produces both the reference signal and the position signal. The position signal is produced at the receiver as soon as the signal from the center station is received. The reference signal reaches the receiver at some later time because it took a longer path via the reference transmitter. If the time difference between the reception

of these two signals could be measured, it would produce two sets of hyperbolas using the same baselines as in the basic system.

There are inherent difficulties in trying to measure this time difference, however. The multivibrator that controls the switching rate in the center transmitter has a slow rise time compared to the time differences involved. In order to distinguish between lanes, a resolution of less than 65 meters is required. This distance is equivalent to about 0.2 microseconds resolution. A second drawback in the method is obvious; to measure time differences on the order of microseconds requires a bandwidth in megahertz, and the differences are only available at audio frequencies through audio filters.

Another method could be investigated using phase comparison techniques. The frequency difference between the red and green halves of the network is arbitrary. Presently, the difference is about 80 khz. If the two halves were separated by some audio frequency other than the ones already in the system, two more hyperbolic grids would be established. The basic frequencies would have to be adjacent assignments to avoid outside interference. This method is similar to LORAC-C which incorporates an additional transmitter to produce the audio signals for a coarse lane network.

V. RESULTS AND RECOMMENDATIONS

The LORAC system of hyperbolic phase comparison has shown to be a feasible and desirable navigation network for use on Monterey Bay. The transmitters and receivers have been reasonably reliable and the majority of failures were attributed to aging components combined with an eight-month inoperative period. If the system is kept in operation, the frequency of failure decreases and the stability of the system improves.

The most significant variational error in the system was caused by changes in the velocity of propagation of the transmitted signals. Direct observation showed a periodic variation due to these changes of plus or minus two dial divisions on the receiver. This variation produces a maximum error in the area of intended operation of plus or minus 20 feet. Since no reference position is required for repeatability of position, a receiver can be returned to a previously held position to within about 20 feet.

If an absolute position is to be determined, the coordinates of the transmitting antennas become important since they are used in the chart-producing program. Until the location of the antenna sites can be more precisely determined, the accuracy of an absolute position found with this LORAC system will be about 100 feet.

Considerable time and effort was spent on chart overlay preparation so that the system can be used for absolute position finding. The

accuracy of the overlays depends mainly on the accuracy of the data read into the program and the stability of the overall system. Sets of overlays have been made for the two most used charts of Monterey Bay, Coast and Geodetic Survey charts 5402 and 5403. On some overlays the lanes were plotted in colors (red and green) corresponding to the color designations of the two halves of the network. The plotting paper used is opaque and performs satisfactorily as an overlay, but clear mylar sheets for the plotter could be obtained if desired. The lanes could be plotted directly on the existing navigation charts, but a new chart would have to be plotted if a change in frequency or antenna location was made.

A general plotting program for the CALCOMP-563 was a secondary result of this project and can be used for any desired line or point plot within the integer limits of the CDC-160 computer.

It is recommended that the LORAC system as presently installed be kept in operation and used in conjunction with the ocean sciences research program at the Postgraduate School. Continued investigations of lane identification and remote control methods may prove valuable, but direct application may present some difficulties since the system is not designed with these features and is about fifteen years old.

Definite consideration should be given to the possibility of replacing the present system with a more reliable and up-to-date LORAC system.

The prepared chart overlays should be compared to actual receiver readings and areas of disagreement investigated. Deviations are to be

expected where the signals pass over land or near large metallic structures. The areas in the vicinity of the transmitting antennas are also of interest.

The number of potential users of a navigational system on Monterey Bay is unlimited. Various research projects are being conducted by a number of organizations and a permanent, reliable navigation system, such as LORAC, would benefit many.

APPENDIX A

DATA PROCESSING PROGRAM

```

100  FORMAT (2I3)
101  FORMAT (2(3F8.2,I4,F8.2,I4,4X))
102  FORMAT (17X,5HGREEN, 40X,3HRED)
103  FORMAT (2(44H;;;AVE;;;RMS;;;;MAX;;TIME;;;MIN;;TIME;;;;))
      DIMENSION IX(60), IY(60)
      PUNCH 102
      PUNCH 103
60    XSUM=0.0
      YSUM=0.0
      DO 10 I=1,60
        READ 100, IX(I), IY(I)
        XSUM=XSUM+IX(I)
        YSUM=YSUM+IY(I)
10    CONTINUE
      XAVE=XSUM/60.0
      YAVE=YSUM/60.0
      XMAX=0.0
      XMIN=1000.
400    DO 20 N=1,60
      IF (XMAX-IX(N)) 300,301,301
300    XMAX=IX(N)
      N1=N
301    IF (XMIN-IX(N)) 20,20,401
401    XMIN=IX(N)
      N2=N
20    CONTINUE
      YMAX=0.0
      YMIN=1000.
600    DO 30 N=1,60
      IF (YMAX-IY(N)) 500,501,501
500    YMAX=IY(N)
      N3=N
501    IF (YMIN-IY(N)) 30,30,601
601    YMIN=IY(N)
      N4=N
30    CONTINUE
      XSQSM=0.0
      DO 40 K=1,60
        XSQ=(XAVE-IX(K))**2
        XSQSM=XSQSM+XSQ

```

```

40    CONTINUE
      XRMS=SQRTF(XSQSM/60.0)
      YSQSM=0.0
      DO 50 K=1,60
        YSQ=(YAVE-IY(K))2
        YSQSM=YSQSM+YSQ
50    CONTINUE
      YRMS=SQRTF(YSQSM/60.0)
      PUNCH 101, XAVE, XRMS, XMAX, N1, XMIN, N2, YAVE, YRMS, YMAX,
x N3, YMIN, N4
      PAUSE 7777
      GO TO 60
      END
      END

```


APPENDIX B

PLOTTING PROGRAM

Memory Location	Instruction Word	Machine Language	Memory Location	Instruction Word	Machine Language
0000	7022	jpi 22	0046	2450	
0001	7023	jpi 23	0047	2466	
0002	7024	jpi 24			
0003	7025	jpi 25	0050	2315	
0004	7026	jpi 26	0051	2350	
0005	7027	jpi 27	0052	0264	
0006	7030	jpi 30	0053	0370	
0007	7031	jpi 31	0054	2400	
			0055	0231	
0010	7500	exc	0056	2200	
0011	1161	1161	0057	2400	
0012	7700	hlt			
0013	0000		0060	0532	
0014	7037	jpi 37	0061	0577	
0015	7036	jpi 36	0062	1325	
0016	7035	jpi 35	0063	1363	
0017	0000		0064	0263	
			0065	0310	
0020	0000		0066	2453	
0021	0000		0067	0100	
0022	2130				
0023	2133		0070	7774	
0024	2136		0071	0000	
0025	2141		0072	4104	
0026	2144		0073	0013	
0027	2147		0074	7703	
			0075	2600	
0030	2152		0076	0076	
0031	2155		0077	7715	
0032	0412	ldn 12			
0033	4161	sti 61	0100	2200	ldc
0034	7067	jpi 67	0101	3000	3000
0035	2351		0102	4213	stf 13
0036	1625		0103	7500	exc
0037	2000		0104	4102	4102
			0105	7600	ina
0040	0000		0106	6401	zjb 01
0041	0000		0107	7600	ina
0042	2534				
0043	2500				
0044	2504				
0045	2530				

0110	0111	ls6		0165	7402	otn	02
0111	4077	std	77	0166	0601	adn	01
0112	7600	ina		0167	6503	nzb	03
0113	5077	rad	77				
0114	4100	stm		0170	2100	ldm	
0115	3000		3000	0171	3001		3001
0116	5701	aob	01	0172	6013	zjf	13
0117	4207	stf	07	0173	6306	njf	06
				0174	0300	nop	
0120	7600	ina		0175	7404	otn	04
0121	0111	ls6		0176	0701	sbn	01
0122	4077	std	77	0177	6503	nzb	03
0123	7600	ina					
0124	5077	rad	77				
0125	4100	stm		0200	6005	zjf	05
0126	3012		0000	0201	0300	nop	
0127	5701	aob	01	0202	7410	otn	10
				0203	0601	adn	01
0130	4313	stb	13	0204	6503	nzb	03
0131	0702	sbn	02	0205	7101	jfi	01
0132	4100	stm		0206	0210		0210
0133	0226		0226	0207	0701		
0134	7600	ina					
0135	6526	nzb	26	0210	2200	ldc	
0136	7101	jfi	01	0211	3000		3000
0137	0150		0150	0212	4221	stf	21
				0213	2200	ldc	
0140	1001			0214	3002		3002
0141	6012			0215	4220	stf	20
0142	6211			0216	2200	ldc	
0143	6311			0217	3001		3001
0144	2100						
0145	1001			0220	4227	stf	27
0146	6007			0221	2200	ldc	
0147	6206			0222	3003		3003
				0223	4226	stf	26
0150	7500	exc		0224	2207	ldf	07
0151	4401		4401	0225	3600	sbc	
0152	7440	otn	40	0226	3236		0000
0153	2100	ldm		0227	6103	nzf	03
0154	3000		3000				
0155	6013	zjf	13	0230	7101	jfi	01
0156	6306	njf	06	0231	0532		0000
0157	7401	otn	01	0232	2500	lcm	
				0233	3236		0000
0160	0300	nop		0234	3100	adm	
0161	0701	sbn	01	0235	3240		0000
0162	6503	nzb	03	0236	4100	stm	
0163	6005	zjf	05	0237	1000		1000
0164	0300	nop					

0240	0300	nop		0316	1001	1001
0241	0300	nop		0317	6015	zjf 15
0242	5707	aob	07	0320	6317	njf 17
0243	5710	aob	10	0321	6215	pjf 15
0244	5707	aob	07	0322	2100	ldm
0245	5710	aob	10	0323	1001	1001
0246	2500	lcm		0324	6012	zjf 12
0247	3237		0000	0325	6211	pjf 11
0250	3100	adm		0326	6311	njf 11
0251	3241		0000	0327	2100	ldm
0252	4100	stm		0330	1001	1001
0253	1001		1001	0331	6007	zjf 07
0254	0300	nop		0332	6206	pjf 06
0255	0300	nop		0333	6306	njf 06
0256	5707	aob	07	0334	7101	jfi 01
0257	5710	aob	10	0335	0224	0224
0260	5707	aob	07	0336	7104	jfi 04
0261	5710	aob	10	0337	7104	jfi 04
0262	7101	jfi	01	0340	7104	jfi 04
0263	0310		0310	0341	7104	jfi 04
0264	2200	ldc		0342	0400	
0265	7401		7401	0343	1200	
0266	4100	stm		0344	0700	
0267	0160		0160	0345	1500	
0270	4100	stm		0346	4100	stm
0271	0551		0551	0347	0201	0201
0272	0601	adn	01	0350	4100	stm
0274	0164		0164	0351	0564	0564
0275	4100	stm		0352	2200	ldc
0276	0544		0544	0353	5100	5100
0277	0602	adn	02	0354	4100	stm
0300	4100	stm		0355	0240	0240
0301	0174		0174	0356	4100	stm
0302	4100	stm		0357	0254	0254
0303	0571		0571	0360	2200	ldc
0304	0604	adn	04	0361	1000	1000
0305	7101	jfi	01	0362	4100	stm
0306	0346		0346	0363	0241	0241
0307	0000			0364	0606	adn 01
0310	2100	ldm		0365	4100	stm
0311	1000		1000	0366	0255	0255
0312	6003	zjf	03	0367	7101	jfi 01
0313	6207	pjf	07			
0314	6313	njf	13			
0315	2100	ldm				

0370	2510		0000	0440	1001		1001
0371	0000			0441	6347	njf	47
0372	0000			0442	6016	zjf	16
0373	0000			0443	6215	pjf	15
0374	0000			0444	0101	pta	
0375	0000			0445	7101	jfi	01
0376	0000			0446	0600		0600
0377	0000			0447	0101	pta	
0400	7500	exc		0450	7101	jfi	01
0401	4401		4401	0451	0403		0403
0402	7420	otn	20	0452	0101	pta	
0403	2100	ldm		0453	7101	jfi	01
0404	1001		1001	0454	0613		0613
0405	3100	adm		0455	0101	pta	
0406	1001		1001	0456	7101	jfi	01
0407	3100	adm		0457	0403		0403
0410	1001		1001	0460	0101	pta	
0411	3500	sbm		0461	7101	jfi	01
0412	1000		1000	0462	0644		0644
0413	6331	njf	31	0463	0101	pta	
0414	6052	zjf	52	0464	7101	jfi	01
0415	3500	sbm		0465	0403		0403
0416	1000		1000	0466	0101	pta	
0417	6347	njf	47	0467	7101	jfi	01
0420	6040	zjf	40	0470	0600		0600
0421	3500	sbm		0471	0101	pta	
0422	1000		1000	0472	7101	jfi	01
0423	6335	njf	35	0473	0644		0644
0424	6034	zjf	34	0474	0101	pta	
0425	2100	ldm		0475	7101	jfi	01
0426	1000		1000	0476	0600		0600
0427	3100	adm		0477	0101	pta	
0430	1000		1000	0500	7101	jfi	01
0431	3100	adm		0501	0644		0644
0432	1000		1000	0502	0101	pta	
0433	3500	sbm		0503	7101	jfi	01
0434	1001		1001	0504	0600		0600
0435	6315	njf	15	0505	0101	pta	
0436	6052	zjf	52	0506	7101	jfi	01
0437	3500	sbm		0507	0403		0403

0510	0101	pta		0550	6005	zjf	05
0511	7101	jfi	01	0551	0300	nop	
0512	0613		0613	0552	7401	otn	01
0513	0101	pta		0553	0601	adn	01
0514	7101	jfi	01	0554	6503	nzb	03
0515	0644		0644	0555	2100	ldm	
0516	0101	pta		0556	0247		0247
0517	7101	jfi	01	0557	4202	stf	02
0520	0613		0613	0560	2100	ldm	
0521	0101	pta		0561	3237		0000
0522	7101	jfi	01	0562	6013	zjf	13
0523	0644		0644	0563	6306	njf	06
0524	0101	pta		0564	0300	nop	
0525	7101	jfi	01	0565	7410	otn	10
0526	0613		0613	0566	0701	sbn	01
0527	0101	pta		0567	6503	nzb	03
0530	7101	jfi	01	0570	6005	zjf	05
0531	0403		0403	0571	0300	nop	
0532	7500	exc		0572	7404	otn	04
0533	4401		4401	0573	0601	adn	01
0534	7440	otn	40	0574	6503	nzb	03
0535	2100	ldm		0575	0300	nop	
0536	0233		0233	0576	7101	jfi	01
0537	4202	stf	02	0577	2523		0000
0540	2100	ldm					
0541	3236		0000				
0542	6013	zjf	13				
0543	6306	njf	06				
0544	0300	nop					
0545	7402	otn	02				
0546	0701	sbn	01				
0547	6503	nzb	03				

0600	0603	adn	03	0650	1000		1000
0601	4211	stf	11	0651	0701	sbn	01
0602	7401	otn	01	0652	4100	stm	
0603	2100	ldm		0653	1000		1000
0604	1000		1000	0654	2100	ldm	
0605	0701	sbn	01	0655	1001		1001
0606	4100	stm		0656	0701	sbn	01
0607	1000		1000	0657	4100	stm	
0610	6025	zjf	25	0660	1001		1001
0611	7101	jfi	01	0661	6433	zjb	33
0612	0447		0447	0662	7101	jfi	01
0613	0603	adn	03	0663	0463		0463
0614	4211	stf	11	0664	0000		
0615	7404	otn	04	0665	0000		
0616	2100	ldm		0666	0000		
0617	1001		1001	0667	0000		
0620	0701	sbn	01	0670	0000		
0621	4100	stm		0671	0000		
0622	1001		1001	0672	0000		
0623	6003	zjf	03	0673	0000		
0624	7101	jfi	01	0674	0000		
0625	0455		0455	0675	0000		
0626	2100	ldm		0676	0000		
0627	1000		1000	0677	0000		
0630	6003	zjf	03	0700	7500	exc	
0631	7101	jfi	01	0701	4401		4401
0632	0403		0403	0702	7420	otn	20
0633	7101	jfi	01	0703	2100	ldm	
0634	0224		0224	0704	1001		1001
0635	2100	ldm		0705	3100	adm	
0636	1001		1001	0706	1001		1001
0637	6003	zjf	03	0707	3100	adm	
0640	7101	jfi	01	0710	1001		1001
0641	0403		0403	0711	3100	adm	
0642	7101	jfi	01	0712	1000		1000
0643	0224		0224	0713	6331	njf	31
0644	0603	adn	03	0714	6047	zjf	47
0645	4216	stf	16	0715	3100	adm	
0646	7405	otn	05	0716	1000		1000
0647	2100	ldm		0717	6344	njf	44

0720	6036	zjf	36	0770	1144		1144
0721	3100	adm		0771	0101	pta	
0722	1000		1000	0772	7101	jfi	01
0723	6333	njf	33	0773	1100		1100
0724	6032	zjf	32	0774	7101	jfi	01
0725	2100	ldm		0775	1002		1002
0726	1000		1000	0776	0000		
0727	3100	adm		0777	0000		
0730	1000		1000	1000	0000		
0731	3100	adm		1001	0000		
0732	1000		1000	1002	0101	pta	
0733	3100	adm		1003	7101	jfi	01
0734	1001		1001	1004	1144		1144
0735	6214	pjf	14	1005	0101	pta	
0736	6054	zjf	54	1006	7101	jfi	01
0737	3100	adm		1007	1100		1100
0740	1001		1001	1010	7101	jfi	01
0741	6251	pjf	51	1011	0703		0703
0742	6014	zjf	14	1012	0101	pta	
0743	6313	njf	13	1013	7101	jfi	01
0744	0101	pta		1014	1113		1113
0745	7101	jfi	01	1015	0101	pta	
0746	1100		1100	1016	7101	jfi	01
0747	7101	jfi	01	1017	1144		1144
0750	0703		0703	1020	0101	pta	
0751	0101	pta		1021	7101	jfi	01
0752	7101	jfi	01	1022	1113		1113
0753	1113		1113	1023	0101	pta	
0754	7101	jfi	01	1024	7101	jfi	01
0755	0703		0703	1025	1144		1144
0756	0101	pta		1026	0101	pta	
0757	7101	jfi	01	1027	7101	jfi	01
0760	1144		1144	1030	1113		1113
0761	7101	jfi	01	1031	7101	jfi	01
0762	0703		0703	1032	0703		0703
0763	0101	pta		1033	0603	adn.	03
0764	7101	jfi	01	1034	4217	stf	17
0765	1100		1100	1035	7440	otn	40
0766	0101	pta		1036	2440	lcd	40
0767	7101	jfi	01	1037	6013	zjf	13

1040	4207	stf	07	1110	6025	zjf	25
1041	2600	lcc		1111	7101	jfi	01
1042	0144		0144	1112	0747		0747
1043	7402	otn	02	1113	0603	adn	03
1044	0601	adn	01	1114	4211	stf	11
1045	6502	nzb	02	1115	7404	otn	04
1046	2200	ldc		1116	2100	ldm	
1047	0000		0000	1117	1001		1001
1050	5701	aob	01	1120	0701	sbn	01
1051	6510	nzb	10	1121	4100	stm	
1052	7101	jfi	01	1122	1001	1001	
1053	1651		1651	1123	6003	zjf	03
1054	0603	adn	03	1124	7101	jfi	01
1055	4217	stf	17	1125	1015		1015
1056	7440	otn	40	1126	2100	ldm	
1057	2441	lcd	41	1127	1000		1000
1060	6013	zjf	13	1130	6003	zjf	03
1061	4207	stf	07	1131	7101	jfi	01
1062	2600	lcc		1132	0703		0703
1063	0144		0144	1133	7101	jfi	01
1064	7404	otn	04	1134	0224		0224
1065	0601	adn	01	1135	2100	ldm	
1066	6502	nzb	02	1136	1001		1001
1067	2200	ldc		1137	6003	zjf	03
1070	0000		0000	1140	7101	jfi	01
1071	5701	aob	01	1141	0703		0703
1072	6510	nzb	10	1142	7101	jfi	01
1073	7101	jfi	01	1143	0224		0224
1074	1673		1673	1144	0603	adn	03
1075	0000			1145	4216	stf	16
1076	0000			1146	7406	otn	06
1077	0000			1147	2100	ldm	
1100	0603	adn	03	1150	1000		1000
1101	4211	stf	11	1151	0601	adn	01
1102	7402	otn	02	1152	4100	stm	
1103	2100	ldm		1153	1000		1000
1104	1000		1000	1154	2100	ldm	
1105	0601	adn	01	1155	1001		1001
1106	4100	stm		1156	0701	sbn	01
1107	1000		1000	1157	4100	stm	

1160	1001		1001	1230	1000		1000
1161	6433	zjb	33	1231	3100	adm	
1162	7101	jfi	01	1232	1000		1000
1163	0761		0761	1233	3100	adm	
1164	0000			1234	1001		1001
1165	0000			1235	6314	njf	14
1166	0000			1236	6046	zjf	46
1167	0000			1237	3100	adm	
1170	0000			1240	1001		1001
1171	0000			1241	6343	njf	43
1172	0000			1242	6014	zjf	14
1173	0000			1243	6213	pjf	13
1174	0000			1244	0101	pta	
1175	0000			1245	7101	jfi	01
1176	0000			1246	1400		1400
1177	0000			1247	7101	jfi	01
1200	7500	exc		1250	1203		1203
1201	4401		4401	1251	0101	pta	
1202	7420	otn	20	1252	7101	jfi	01
1203	2100	ldm		1253	1413		1413
1204	1001		1001	1254	7101	jfi	01
1205	3100	adm		1255	1203		1203
1206	1001		1001	1256	0101	pta	
1207	3100	adm		1257	7101	jfi	01
1210	1001		1001	1260	1444		1444
1211	3100	adm		1261	7101	jfi	01
1212	1000		1000	1262	1203		1203
1213	6231	pjf	31	1263	0101	pta	
1214	6047	zjf	47	1264	7101	jfi	01
1215	3100	adm		1265	1400		1400
1216	1000		1000	1266	0101	pta	
1217	6244	pjf	44	1267	7101	jfi	01
1220	6036	zjf	36	1270	1444		1444
1221	3100	adm		1271	0101	pta	
1222	1000		1000	1272	7101	jfi	01
1223	6233	pjf	33	1273	1400		1400
1224	6032	zjf	32	1274	0101	pta	
1225	2100	ldm		1275	7101	jfi	01
1226	1000		1000	1276	1444		1444
1227	3100	adm		1277	0101	pta	

1300	7101	jfi	01	1350	6502	nzb	02
1301	1400		1400	1351	2200	ldc	
1302	7101	jfi	01	1352	0024		0024
1303	1203		1203	1353	7410	otn	10
1304	0101	pta		1354	0701	sbn	01
1305	7101	jfi	01	1355	6502	nzb	02
1306	1413		1413	1356	0412	ldn	12
1307	0101	pta		1357	7404	otn	05
1310	7101	jfi	01	1360	0701	sbn	01
1311	1444		1444	1361	6502	nzb	02
1312	0101	pta		1362	7101	jfi	01
1313	7101	jfi	01	1363	0532		0000
1314	1413		1413	1364	0000		
1315	0101	pta		1365	0000		
1316	7101	jfi	01	1366	0000		
1317	1444		1444	1367	0000		
1320	0101	pta		1370	0000		
1321	7101	jfi	01	1371	0000		
1322	1413		1413	1372	0000		
1323	7101	jfi	01	1373	0000		
1324	1203		1203	1374	0000		
1325	7500	exc		1375	0000		
1326	4401		4401	1376	0000		
1327	7420	otn	20	1377	0000		
1330	0412	ldn	12	1400	0603	adn	03
1331	7401	otn	01	1401	4211	stf	11
1332	0701	sbn	01	1402	7401	otn	01
1333	6502	nzb	02	1403	2100	ldm	
1334	2200	ldc		1404	1000		1000
1335	0024		0024	1405	0701	sbn	01
1336	7402	otn	02	1406	4100	stm	
1337	0701	sbn	01	1407	1000		1000
1340	6502	nzb	02	1410	6025	zjf	25
1341	0412	ldn	12	1411	7101	jfi	01
1342	7401	otn	01	1412	1266		1266
1343	0701	sbn	01	1413	0603	adn	03
1344	6502	nzb	02	1414	4211	stf	11
1345	0412	ldn	12	1415	7410	otn	10
1346	7404	otn	04	1416	2100	ldm	
1347	0701	sbn	01	1417	1001		1001

1420	0601	adn	01	1470	0000		
1421	4100	stm		1471	0000		
1422	1001		1001	1472	0000		
1423	6003	zjf	03	1473	0000		
1424	7101	jfi	01	1474	0000		
1425	1254		1254	1475	0000		
1426	2100	ldm		1476	0000		
1427	1000		1000	1477	0000		
1430	6003	zjf	03	1500	7500	exc	
1431	7101	jfi	01	1501	4401		4401
1432	1203		1203	1502	7420	otn	20
1433	7101	jfi	01	1503	2100	ldm	
1434	0224		0224	1504	1001		1001
1435	2100	ldm		1505	3100	adm	
1436	1001		1001	1506	1001		1001
1437	6003	zjf	03	1507	3100	adm	
1440	7101	jfi	01	1510	1000		1000
1441	1203		1203	1511	3500	sbm	
1442	7101	jfi	01	1512	1000		1000
1443	0224		0224	1513	6231	pjf	31
1444	0603	adn	03	1514	6047	zjf	47
1445	4216	stf	16	1515	3500	sbm	
1446	7411	otn	11	1516	1000		1000
1447	2100	ldm		1517	6244	pjf	44
1450	1000		1000	1520	6036	zjf	36
1451	0701	sbn	01	1521	3500	sbm	
1452	4100	stm		1522	1000		1000
1453	1000		1000	1523	6233	pjf	33
1454	2100	ldm		1524	6032	zjf	32
1455	1001		1001	1525	2100	ldm	
1456	0601	adn	01	1526	1000		1000
1457	4100	stm		1527	3100	adm	
1460	1001		1001	1530	1000		1000
1461	6433	zjb	33	1531	3100	adm	
1462	7101	jfi	01	1532	1000		1000
1463	1261		1261	1533	3500	abm	
1464	0000			1534	1001		1001
1465	0000			1535	6214	pjf	14
1466	0000			1536	6046	zjf	46
1467	0000			1537	3500	sbm	

1540	1001		1001	1610	7101	jfi	01
1541	6243	pjf	43	1611	1744		1744
1542	6014	zjf	14	1612	0101	pta	
1543	6313	njf	13	1613	7101	jfi	01
1544	0101	pta		1614	1713		1713
1545	7101	jfi	01	1615	0101	pta	
1546	1700		1700	1616	7101	jfi	01
1547	7101	jfi	01	1617	1744		1744
1550	1503		1503	1620	0101	pta	
1551	0101	pta		1621	7101	jfi	01
1552	7101	jfi	01	1622	1713		1713
1553	1713		1713	1623	7101	jfi	01
1554	7101	jfi	01	1624	1503		1503
1555	1503		1503	1625	7500	exc	
1556	0101	pta		1626	4401		4401
1557	7101	jfi	01	1627	0101	pta	
1560	1744		1744	1630	7101	jfi	01
1561	7101	jfi	01	1631	1033		1033
1562	1503		1503	1632	7420	otn	20
1563	0101	pta		1633	2440	lcd	40
1564	7101	jfi	01	1634	4207	stf	07
1565	1700		1700	1635	2600	lcc	
1566	0101	pta		1636	0310		0310
1567	7101	jfi	01	1637	7401	otn	01
1570	1744		1744	1640	0601	adn	01
1571	0101	pta		1641	6502	nzb	02
1572	7101	jfi	01	1642	2200	ldc	
1573	1700		1700	1643	0000		0000
1574	0101	pta		1644	5701	aob	01
1575	7101	jfi	01	1645	6510	nzb	10
1576	1744		1744	1646	0101	pta	
1577	0101	pta		1647	7101	jfi	01
1600	7101	jfi	01	1650	1033		1033
1601	1700		1700	1651	0101	pta	
1602	7101	jfi	01	1652	7101	jfi	01
1603	1503		1503	1653	1054		1054
1604	0101	pta		1654	7420	otn	20
1605	7101	jfi	01	1655	2441	lcd	41
1606	1713		1713	1656	4207	stf	07
1607	0101	pta		1657	2600	lcc	

1660	0310		0310	1730	6003	zjf	03
1661	7410	otn	10	1731	7101	jfi	01
1662	0601	adn	01	1732	1503		1503
1663	6502	nzb	02	1733	7101	jfi	01
1664	2200	ldc		1734	0224		0224
1665	0000		0000	1735	2100	ldm	
1666	5701	aob	01	1736	1001		1001
1667	6510	nzb	10	1737	6003	zjf	03
1670	0101	pta		1740	7101	jfi	01
1671	7101	jfi	01	1741	1503		1503
1672	1054		1054	1742	7101	jfi	01
1673	7700	hlt		1743	0224		0224
1674	0000			1744	0603	adn	03
1675	0000			1745	4216	stf	16
1676	0000			1746	7412	otn	12
1677	0000			1747	2100	ldm	
1700	0603	adn	03	1750	1000		1000
1701	4211	stf	11	1751	0601	adn	01
1702	7402	otn	02	1752	4100	stm	
1703	2100	ldm		1753	1000		1000
1704	1000		1000	1754	2100	ldm	
1705	0601	adn	01	1755	1001		1001
1706	4100	stm		1756	0601	adn	01
1707	1000		1000	1757	4100	stm	
1710	6025	zjf	25	1760	1001		1001
1711	7101	jfi	01	1761	6433	zjb	33
1712	1566		1566	1762	7101	jfi	01
1713	0603	adn	03	1763	1571		1571
1714	4211	stf	11	1764	0000		
1715	7410	otn	10	1765	0000		
1716	2100	ldm		1766	0000		
1717	1001		1001	1767	0000		
1720	0601	adn	01	1770	0000		
1721	4100	stm		1771	0000		
1722	1001		1001	1772	0000		
1723	6003	zjf	03	1773	0000		
1724	7101	jfi	01	1774	0000		
1725	1607		1607	1775	0000		
1726	2100	ldm		1776	0000		
1727	1000		1000	1777	0000		

2000	7500	exc		2050	6510	nzb	10
2001	4401		4401	2051	2420	lcd	20
2002	7440	otn	40	2052	4207	stf	07
2003	2421	lcd	21	2053	2600	lcc	
2004	6013	zjf	13	2054	0310		0310
2005	4207	stf	07	2055	7402	otn	02
2006	2600	lcc		2056	0601	adn	01
2007	0144		0144	2057	6502	nzb	02
2010	7410	otn	10	2060	2200	ldc	
2011	0601	adn	01	2061	0000		0000
2012	6502	nzb	02	2062	5701	aob	01
2013	2200	ldc		2063	6510	nzb	10
2014	7766		0000	2064	2421	lcd	21
2015	5701	aob	01	2065	4207	stf	07
2016	6510	nzb	10	2066	2600	lcc	
2017	2420	lcd	20	2067	0310		0310
2020	6015	zjf	15	2070	7410	otn	10
2021	4210	stf	10	2071	0601	adn	01
2022	7420	otn	20	2072	6502	nzb	02
2023	2600	lcc		2073	2200	ldc	
2024	0144		0144	2074	0000		0000
2025	7401	otn	01	2075	5701	aob	01
2026	0601	adn	01	2076	6510	nzb	10
2027	6502	nzb	02	2077	2420	lcd	20
2030	2200	ldc		2100	4207	stf	07
2031	0000		0000	2101	2600	lcc	
2032	5701	aob	01	2102	0144		0144
2033	6510	nzb	10	2103	7401	otn	01
2034	6002	zjf	02	2104	0601	adn	01
2035	7700	hlt		2105	6502	nzb	02
2036	2421	lcd	21	2106	2200	ldc	
2037	4207	stf	07	2107	0000		0000
2040	2600	lcc		2110	5701	aob	01
2041	0310		0310	2111	6510	nzb	10
2042	7404	otn	04	2112	7440	otn	40
2043	0601	adn	01	2113	2421	lcd	21
2044	6502	nzb	02	2114	4207	stf	07
2045	2200	ldc		2115	2600	lcc	
2046	0000		0000	2116	0144		0144
2047	5701	aob	01	2117	7404	otn	04

2120	0601	adn	01	2170	0000		
2121	6502	nzb	02	2171	0000		
2122	2200	ldc		2172	0000		
2123	0000		0000	2173	0000		
2124	5701	aob	01	2174	0000		
2125	6510	nzb	10	2175	0000		
2126	7700	hlt		2176	0000		
2127	0000			2177	0000		
2130	2057	ldd	57	2200	7500	exc	
2131	4054	std	54	2201	4102		4102
2132	7044	jpi	44	2202	2200	ldc	
2133	2057	ldd	57	2203	3000		3000
2134	4054	std	54	2204	4070	std	70
2135	7043	jpi	43	2205	7600	ina	
2136	2057	ldd	57	2206	6401	zjb	01
2137	4054	std	54	2207	0111	ls6	
2140	7042	jpi	42	2210	4076	std	76
2141	2057	ldd	57	2211	7600	ina	
2142	4054	std	54	2212	5076	rad	76
2143	7045	jpi	45	2213	1600	scc	
2144	2056	ldd	56	2214	5725		5725
2145	4054	std	54	2215	6112	nzf	12
2146	7044	jpi	44	2216	7600	ina	
2147	2056	ldd	56	2217	0111	ls6	
2150	4054	std	54	2220	4076	std	76
2151	7043	jpi	43	2221	7600	ina	
2152	2056	ldd	56	2222	5076	rad	76
2153	4054	std	54	2223	1600	scc	
2154	7042	jpi	42	2224	4626		4626
2155	2056	ldd	56	2225	6046	zjf	46
2156	4054	std	54	2226	6103	nzf	03
2157	7045	jpi	45	2227	7600	ina	
2160	0000			2230	7600	ina	
2161	0000			2231	7600	ina	
2162	0000			2232	7600	ina	
2163	0000			2233	7600	ina	
2164	0000			2234	7600	ina	
2165	0000			2235	0532	lcn	32
2166	0000			2236	4075	std	75
2167	0000			2237	7600	ina	

2240	4074	std	74	2310	2304	ldb	04
2241	3600	sbc		2311	4100	stm	
2242	0100		0100	2312	0226		0226
2243	6302	njf	02	2313	7101	jfi	01
2244	4074	std	74	2314	0150		0150
2245	2074	ldd	74	2315	2200	ldc	
2246	0111	ls6		2316	0300		0300
2247	4077	std	77	2317	4100	stm	
2250	7600	ina		2320	0160		0160
2251	4074	std	74	2321	4100	stm	
2252	3600	sbc		2322	0164		0164
2253	0100		0100	2323	4100	stm	
2254	6302	njf	02	2324	0174		0174
2255	4074	std	74	2325	4100	stm	
2256	2074	ldd	74	2326	0201		0201
2257	5077	rad	77	2327	4100	stm	
2260	4170	sti	70	2330	0240		0240
2261	5470	aod	70	2331	4100	stm	
2262	5475	aod	75	2332	0241		0241
2263	7600	ina		2333	4100	stm	
2264	6524	nzb	24	2334	0254		0254
2265	0524	lcn	24	2335	4100	stm	
2266	4077	std	77	2336	0255		0255
2267	7600	ina		2337	4100	stm	
2270	6561	nzb	61	2340	0544		0544
2271	5477	aod	77	2341	4100	stm	
2272	6503	nzb	03	2342	0551		0551
2273	2075	ldd	75	2343	4100	stm	
2274	6004	zjf	04	2344	0564		0564
2275	2070	ldd	70	2345	4100	stm	
2276	0702	sbn	02	2346	0571		0571
2277	6112	nzf	12	2347	7101	jfi	01
2300	2070	ldd	70	2350	2510		0000
2301	0702	sbn	02	2351	7500	exc	
2302	4202	stf	02	2352	4401		4401
2303	2100	ldm		2353	7440	otn	40
2304	4004		0000	2354	2600	lcc	
2305	6103	nzf	03	2355	3720		3720
2306	2302	ldb	02	2356	7402	otn	02
2307	6506	nzb	06	2357	7402	otn	02

2360	7402	otn	02
2361	0601	adn	01
2362	6504	nzb	04
2363	2600	lcc	
2364	2703		2703
2365	7401	otn	01
2366	7401	otn	01
2367	0601	adn	01

2370	6503	nzb	03
2371	7101	jfi	01
2372	0000		0000
2373	0000		
2374	0000		
2375	0000		
2376	0000		
2377	0000		

2400	2200	ldc	
2401	3000		3000
2402	4206	stf	06
2403	7500	exc	
2404	2131		2131
2405	7203	inp	03
2406	7770		7770
2407	6102	nzf	02

2410	3240		0000
2411	4071	std	71
2412	7500	exc	
2413	1141		1141
2414	7600	ina	
2415	0320	scn	20
2416	6022	zjf	22
2417	0533	lcn	33

2420	4075	std	75
2421	2311	ldb	11
2422	4070	std	70
2423	0604	adn	04
2424	4073	std	73
2425	2173	ldi	73
2426	4170	sti	70
2427	5470	aod	70

2430	5475	aod	75
2431	5473	aod	73
2432	1471	acd	71
2433	6506	nzb	06
2434	2071	ldd	71
2435	0705	sbn	05
2436	4326	stb	26
2437	6534	nzb	34

2440	2070	ldd	70
2441	0701	abn	01
2442	4070	std	70
2443	7101	jfi	01
2444	2273		2273
2445	2100		
2446	0226		
2447	0602		

2450	2200	ldc	
2451	7440		7440
2452	6103	nzf	03
2453	2200	ldc	
2454	7420		7420
2455	4100	stm	
2456	0402		0402
2457	4100	stm	

2460	0702		0702
2461	4100	stm	
2462	1202		1202
2463	4100	stm	
2464	1502		1502
2465	7101	jfi	01
2466	2514		0000
2467	0000		

2470	0000		
2471	0000		
2472	0000		
2473	0000		
2474	0000		
2475	0000		
2476	0000		
2477	0000		

2500	0101	pta		2550	4164	sti	64
2501	0610	adn	10	2551	2065	ldd	65
2502	4153	sti	53	2552	4163	sti	63
2503	7052	jpi	52	2553	7054	jpi	54
2504	0101	pta		2554	2060	ldd	60
2505	0604	adn	04	2555	4163	sti	63
2506	4151	sti	51	2556	0101	pta	
2507	7050	jpi	50	2557	0604	adn	04
2510	0101	pta		2560	4161	sti	61
2511	0604	adn	04	2561	7062	jpi	62
2512	4147	sti	47	2562	7700	hlt	
2513	7066	jpi	66	2563	7101	jfi	01
2514	2060	ldd	60	2564	2544		2544
2515	4155	sti	55	2565	0000		
2516	2065	ldd	65	2566	0000		
2517	4164	sti	64	2567	0000		
2520	0101	pta		2570	0000		
2521	0603	adn	03	2571	0000		
2522	4161	sti	61	2572	0000		
2523	7054	jpi	54	2573	0000		
2524	0000			2574	0000		
2525	0000			2575	0000		
2526	0000			2576	0000		
2527	0000			2577	0000		
2530	0101	pta					
2531	0610	adn	10				
2532	4153	sti	53				
2533	7052	jpi	52				
2534	0101	pta					
2535	0604	adn	04				
2536	4151	sti	51				
2537	7050	jpi	50				
2540	0101	pta					
2541	0604	adn	04				
2542	4147	sti	47				
2543	7046	jpi	46				
2544	0101	pta					
2545	0610	adn	10				
2546	4155	sti	55				
2547	2062	ldd	62				

LORAC GRID GENERATION PROGRAM

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    DIMENSION FREQ(2), BASE(2), HBASE(2), COSA(2), SINA(2),
    *WIDTH(2), TOTAL(2), MIDLN(2), ZH(2), ZK(2), X(1500),
    *Y(1500), CENFR(2), FREQM(2),
    *CI(100), CVII(100), CVIII(100), CIX(100), CX(100)
    READ(5,101) GREENX, GREENY, CENTERX, CENTERY, REDX, REDY,
    *FREQ(1), FREQ(2), CENFR(1), CENFR(2), FREQM(1), FREQM(2),
    *VELPROP
    READ(5,103) L1, L2
    READ(5,105) CI(K), CVII(K), CVIII(K), CIX(K), CX(K),
    *K=L1, L2
    MIDLN(1)=1000
    MIDLN(2)=2000
COORDINATES OF THE MIDPOINTS
    ZH(1)=0.5*(CENTERX+GREENX)
    ZK(1)=0.5*(CENTERY+GREENY)
    ZH(2)=0.5*(CENTERX+REDX)
    ZK(2)=0.5*(CENTERY+REDY)
BASELINE LENGTHS
    GRNDX=GREENX-CENTERX
    GRNDY=GREENY-CENTERY
    REDDX=REDX-CENTERX
    REDDY=REDY-CENTERY
    BASE(1)=SQRT(GRNDX**2+GRNDY**2)
    BASE(2)=SQRT(REDDX**2+REDDY**2)
    HBASE(1)=BASE(1)/2.0
    HBASE(2)=BASE(2)/2.0
    COSA(1)=GRNDX/BASE(1)
    SINA(1)=GRNDY/BASE(1)
    COSA(2)=REDDX/BASE(2)
    SINA(2)=REDDY/BASE(2)
DETERMINE LANE WIDTHS
    WIDTH(1)=VELPROP/(FREQ(1)+CENFR(1))
    WIDTH(2)=VELPROP/(FREQ(2)+CENFR(2))
COMPUTE THE TOTAL NUMBER OF LANES
    TOTAL(1)=BASE(1)/WIDTH(1)
    TOTAL(2)=BASE(2)/WIDTH(2)
FIND THE LANE NUMBERS AT EACH STATION
    GCENLANE=MIDLN(1)-TOTAL(1)/2.0
    GENDLANE=MIDLN(1)+TOTAL(1)/2.0
    RCENLANE=MIDLN(2)-TOTAL(2)/2.0
    RENDLANE=MIDLN(2)+TOTAL(2)/2.0
INTRODUCE THE CHART PARAMETERS
    IPLOT=1
1000 READ(5,102) XMIN, XMAX, YMIN, YMAX, XSCALE, YSCALE, DELU,
    *UMAX, M
    OUTPUT(6) IPLOT
    MWIDE=(XMAX-XMIN)/1.243
    MHIGH=YMAX-YMIN
    IWIDE=MWIDE/XSCALE
    IHIGH=MHIGH/YSCALE
    OUTPUT(6) IWIDE, IHIGH
OUTPUT STATION COORDINATES FOR PLOTTING
    X(1)=GREENX
    Y(1)=GREENY
    IPS=1
    CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
    IPC=1
    X(1)=(X(1)-XMIN)/1.243
    Y(1)=Y(1)-YMIN
    CALL TAPEJUT(X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
    X(1)=CENTERX
    Y(1)=CENTERY
    IPS=1
    CALL CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
    IPC=1
    X(1)=(X(1)-XMIN)/1.243
    Y(1)=Y(1)-YMIN
    CALL TAPEJUT(X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
    X(1)=REDX
    Y(1)=REDY

```

```

IPS=1
CALL CONVERT(X,Y,C1,CVII,CVIII,CIX,CX,L1,L2,IPS)
IPC=1
X(1)=(X(1)-XMIN)/1.243
Y(1)=Y(1)-YMIN
CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
CALCULATE THE NUMBER OF POINTS PER LINE
IF(UMAX.NE.0.0)GO TO 20
UMAX=2.0
20 ICALC=UMAX/DELU+1.0
ICALM=ICALC-1
CALCULATE THE POINTS TO BE PLOTTED, LANE BY LANE
DO 100, K=1,2
NCALC=(TOTAL(K)/(2*M)+1
NCALM=NCALC-1
FIND LANE NUMBER OF THE FIRST LANE TO BE PLOTTED
DO 200, L=1,NCALC
LANE=MIDLN(K)-(NCALC-L)*M
A=(MIDLN(K)-LANE)*WIDTH(K)
B=SQRT(HBASE(K)**2-A**2)
OUTPUT(6) LANE
CALCULATE POINTS IN THE SECOND QUADRANT
IP=1
DO 300 IMU=1,ICALC
U=UMAX-(IMU-1)*DELU
E1=A*COSH(U)*COSA(K)
N1=A*COSH(U)*SINA(K)
E2=B*SINH(U)*SINA(K)
N2=B*SINH(U)*COSA(K)
XX=ZH(K)-E1-E2
YY=ZK(K)-N1+N2
X(IP)=XX
Y(IP)=YY
IPS=IP
IP=IP+1
300 CONTINUE
CALCULATE THE POINTS IN THE THIRD QUADRANT
DO 400 IMU=1,ICALM
U=UMAX-(ICALM-IMU)*DELU
E1=A*COSH(U)*COSA(K)
N1=A*COSH(U)*SINA(K)
E2=B*SINH(U)*SINA(K)
N2=B*SINH(U)*COSA(K)
XX=ZH(K)-E1+E2
YY=ZK(K)-N1-N2
X(IP)=XX
Y(IP)=YY
IPS=IP
IP=IP+1
400 CONTINUE
CALL CONVERT(X,Y,C1,CVII,CVIII,CIX,CX,L1,L2,IPS)
IPC=0
DO 30 N=1,IPS
IF(.NOT.((XMIN.LE.X(N).LE.XMAX).AND.
*(YMIN.LE.Y(N).LE.YMAX)))GO TO 30
IPC=IPC+1
X(IPC)=(X(N)-XMIN)/1.243
Y(IPC)=Y(N)-YMIN
30 CONTINUE
IF(IPC.LE.1)GO TO 200
CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
200 CONTINUE
DO 500 L=1,NCALM
LANE=MIDLN(K)+L*M
A=(LANE-MIDLN(K))*WIDTH(K)
B=SQRT(HBASE(K)**2-A*A)
OUTPUT(6) LANE
IP=1
CALCULATE POINTS IN THE FIRST QUADRANT
DO 600 IMU=1,ICALC
U=UMAX-(IMU-1)*DELU
E1=A*COSH(U)*COSA(K)

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N1=A*COSH(U)*SINA(K)
E2=B*SINH(U)*SINA(K)
N2=B*SINH(U)*COSA(K)
XX=ZH(K)+E1-E2
YY=ZK(K)+N1+N2
X(IP)=XX
Y(IP)=YY
IPS=IP
IP=IP+1
600 CONTINUE
CALCULATE POINTS FOR THE FOURTH QUADRANT
DO 700 IMU=1,ICALM
U=UMAX-(ICALM-IMU)*DELU
E1=A*COSH(U)*COSA(K)
N1=A*COSH(U)*SINA(K)
E2=B*SINH(U)*SINA(K)
N2=B*SINH(U)*COSA(K)
XX=ZH(K)+E1+E2
YY=ZK(K)+N1-N2
X(IP)=XX
Y(IP)=YY
IPS=IP
IP=IP+1
700 CONTINUE
CALL CONVERT(X,Y,C1,CVII,CVIII,CIX,CX,L1,L2,IPS)
IPC=0
DO 40 N=1,IPS
IF(.NOT.((XMIN.LE.X(N).LE.XMAX).AND.
*(YMIN.LE.Y(N).LE.YMAX)))GO TO 40
IPC=IPC+1
X(IPC)=(X(N)-XMIN)/1.243
Y(IPC)=Y(N)-YMIN
40 CONTINUE
IF(IPC.LE.1)GO TO 500
CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
500 CONTINUE
100 CONTINUE
DO 75 N=1,20
X(N)=(N-1)*MWIDE/20.
75 Y(N)=0.
DO 76 N=21,40
X(N)=MWIDE
76 Y(N)=(N-21)*MHIGH/20.
DO 77 N=41,60
X(N)=(60-N)*MWIDE/19.
77 Y(N)=MHIGH
DO 78 N=61,80
X(N)=0.
78 Y(N)=(80-N)*MHIGH/20.
IPC=80
CALL TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
IPLOT=IPLOT+1
GO TO 1000
101 FORMAT(2F20.1)
102 FORMAT(6F10.2,2F6.3,I3)
103 FORMAT(2I3)
105 FORMAT(5F12.3)
END

SUBROUTINE TAPEOUT (X,Y,IPC,XSCALE,YSCALE,MWIDE,MHIGH)
DIMENSION IX(1500),IY(1500),IXY(1500),X(1500),Y(1500)
DO 25 N=1,IPC
IX(N)=(X(N)-MWIDE/2.0)/XSCALE
IY(N)=(Y(N)-MHIGH/2.0)/YSCALE
IF(-2047.LT.IX(N)) GO TO 1
IX(N)=-2047
1 IF(2047.GT.IX(N))GO TO 2
IX(N)=2047
2 IF(-2047.LT.IY(N))GO TO 3
IY(N)=-2047
3 IF(2047.GT.IY(N))GO TO 4

```



```

4      IY(N)=2047
      IF(IX(N).GE.0)GO TO 5
5      IX(N)=IX(N)+4095
      IX(N)=IX(N)*4096
      IF(IY(N).GE.0)GO TO 6
      IY(N)=IY(N)+4095
6      IXY(N)=IX(N)+IY(N)
25     CONTINUE
      DO 10 I=1,10
      IF(((I-1)*128.LE.IPC).AND.(((I-1)*128+13).GT.IPC))
*GO TO 15
10     CONTINUE
      GO TO 7
15     DO 20 K=(IPC+1),((I-1)*128+13)
20     IXY(K)=0
      IPC=(I-1)*128+13
7      WRITE (4) IXY(N), N=1,IPC
      END FILE 4
      RETURN
      END

```

```

      SUBROUTINE CONVERT(X,Y,CI,CVII,CVIII,CIX,CX,L1,L2,IPS)
      DIMENSION X(1500),Y(1500),CI(100),CVII(100),
*CVIII(100),CIX(100),CX(100)
      DO 17 N=1,IPS
      E=X(N)-500000.
      Q=E*1.E-06
      QSQ=Q*Q
      QCUBE=QSQ*Q
      QFOURTH=QCUBE*Q
      IF(Y(N).GT.CI(L1))GO TO 14
      Y(N)=CI(L1)
      X(N)=0.
      GO TO 17
14     IF(Y(N).LT.CI(L2))GO TO 16
      Y(N)=CI(L2)
      X(N)=0.
      GO TO 17
16     DO 27 K=L1,L2
      IF(Y(N).LE.CI(K))GO TO 28
27     CONTINUE
28     L=K-1
      DELTA=(Y(N)-CI(L))/(CI(K)-CI(L))
      YP=(L-1)*60.+DELTA*60.
      DVII=CVII(L)+DELTA*(CVII(K)-CVII(L))
      Y(N)=(YP-DVII*QSQ+CVIII(L)*QFOURTH)*100.
      DIX=CIX(L)+DELTA*(CIX(K)-CIX(L))
      DX=CX(L)+DELTA*(CX(K)-CX(L))
      X(N)=(DIX*Q-DX*QCUBE)*100.
17     CONTINUE
      RETURN
      END

```

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13. ABSTRACT			
<p>A LORAC system of navigation has been established in the Monterey Bay area and is intended for use in the field of ocean sciences research. It operates on a phase comparison principle and provides highly accurate navigational fixes without complex timing circuitry. Short-term phase stability of the system was studied and methods of remote control and lane identification were investigated. Some equipment modifications were made to incorporate desirable features in the system, but further modernization may be necessary if long periods of continued use are expected. A general plotting program for the CALCOMP-563 plotter was written to produce chart overlays for existing navigational charts and is included as Appendix B. The overlays can be tailored to fit any scale chart in the area of intended operation and the inputs to the grid generation program can be varied if the system parameters are changed.</p>			

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